FEARS STRUCTURAL ENGINEERING LABORATORY

GENERAL QUASI-STATIC SEISMIC ANALYSIS
OF BURIED STRAIGHT PIPING SYSTEMS

by

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and

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To assist the seismic analysis and design of buried pipeline in a seismic environment, a comprehensive non-linear quasi-static analysis model was developed. The analysis includes non-linear elasto-plastic behavior of soil and joint springs. A general computer program was devised to accept most influential parameters. This program, capable of handling continuous as well segmented pipelines, was tested with various physical, geological and seismological parameters. The physical parameters are pipe material elasticity, diameter and thickness, segment length, joint spring constant and maximum strength (yield displacement), soil spring constant and slippage strength (slippage displacement). The geological and seismological parameters include wave propagation speeds and earthquake ground displacement time history. A User's Manual for the computer program is provided.

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Buried pipelines
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ABSTRACT

Past experiences have shown that, seismic excitation during an earthquake in the axial direction of a buried pipeline cause more damage to the pipeline that the seismic excitation in the transverse direction. Hence, most of the past research works have focused on the effects in the axial directions.

To assist the seismic analysis and design of buried pipeline in a seismic environment, a comprehensive non-linear quasi-static analysis model has been developed. A general computer program to accept most, if not all influential parameters, has been written and tested. The analysis includes non-linear elasto-plastic behavior of soil and joint springs. The general computer program can handle continuous, as well as segmented pipelines, with various physical, geological and seismological parameters. The physical parameters are pipe material elasticity, diameter and thickness, segment length, joint spring constant and maximum strength (yield displacement), soil spring constant and slippage strength (slippage displacement). The geological and seismological parameters are wave propagation speeds and earthquake ground displacement time history, among others.

This report consists of three parts. In Part I of this report, a general description of this model is presented. This computer program has been used to investigate the response behavior of buried pipelines with changes in some physical, geo-technical, and seismological parameters. The results are presented in Part II of this report.

A User's Manual for the computer program usage, with some descriptions of the program is contained in Part III of this report.

NOMENCLATURE

E	- Young's modulus of the pipe material
L_i	- Length of i^{th} pipe segment
A_i	- Cross sectional area of i^{th} pipe segment
K_i	- The i^{th} joint spring constant
k_i	- Axial soil resistant spring constant along i^{th} pipe segment
n	- Total number of pipe segments
δ_J	- Maximum elastic joint displacements
δ_S	- Maximum elastic soil displacement
V	- Wave propagation velocity
F	- Elastic force applied to the pipe by the soil
$\{X\}$	- Ends displacement vector of the pipeline segments
$\{X_G\}$	- Ground displacement vector
$[K_{soil}]$	- Soil resistance matrix
$[K_{system}]$	- Structural system matrix

INTRODUCTION

When an earthquake strikes, severe damages are usually done to life line structures, such as, broken water pipelines, sewer pipelines, oil and gas pipelines, etc. The fire that follows, due to broken gas lines and others alike, goes on uncontrolled causing more damages to properties and claiming lifes, because of broken water supply system (1). A better understanding of the response behavior of buried pipeline due to such siesmic ground excitation is necessary to aid in future designs to provide better resistance and reduce damages.

Past observations (6,7) of actual earthquake damage to buried pipelines show axial stresses resulting in joint pull-outs, crushing or buckling of pipes as the most common modes of failure. The intensity of the response behaviors of buried pipelines is influenced by: the physical parameters, such as, pipe diameter, thickness of the pipes, pipe segment length, joint stiffness, and Young's modulus; the geotechnical parameters, such as, the stiffness of the surrounding pipeline, and wave propagation velocity; the seismological parameters, such as, the duration, form, and amplitude of the wave.

The main objective of this project is to investigate the response behavior of buried pipelines due to various physical, geotechnical and seismological parameters mentioned above by extending the computer program based on the quasi-static analysis formulations by Dr. L.R. Wang (4,5) and written by Serna (4). For the convenience of future application, a user's manual is also provided.

PART I

QUASI-STATIC ELASTO-PLASTIC ANALYSIS MODEL

I.1 Preface

In earlier investigations, a quasi-static analysis model was developed to study parametrically the response of elastic buried pipelines, segmented or continuous, subjected to earthquake motion in the axial direction [4]. Based on this model, a more rigorous quasi-static elasto-plastic analysis model was developed [3,5].

The quasi-static elasto-plastic analysis considers that the variation of siesmic wave (by inputing the ground displacement time function) in the system is unchanged when it traverses along the pipe, i.e. the entire pipeline is under a uniform (constant) seismic environment. This restriction has been removed in this investigation. The pipe material is considered to be linearly elastic. The resistant characteristics of the joints and soil to pipe motion are considered to be elasto-plastic.

I.2 Quasi-static approach

I.2.1 Description of the General Model

A long buried piping sytem consisting of n-segments is shown in Figure I.1, where K_1, K_2, ..K_i, ..K_{n-1} are elastic-plastic springs at the joints between pipe segments, in which its resistant characteristic is shown in Figure I.2, and K_0, K_n are springs at the end supports; X_1, X_2, ..X_{2i-1}, S_{2i},

.. X_{2n-1}, X_{2n} are longitudinal displacements at the ends of pipe segments; X_{G1}, X_{G2}, .. X_{Gn-1} are the corresponding ground displacements at the segment intersections in the same direction as the pipeline axis; X_{GO} and X_{Gn} are the ground movements at the ends; L_1, L_2, .. L_i, .. l_n are pipe lengths; and k_1, k_2, .. k_i, .. k_n are soil resistant springs (elastic-plastic as shown in Fig. I.3) per unit length along the segments.

I.2.2 Method of Analysis

The energy method was used to approach the "Quasi-Static Analysis Formulation for Straight Buried Piping Systems" by L. R. Wang (4,5). The detail of the analysis is contained in his report, and therefore will not be repeated here.

Basically, total potential energy of the buried piping system is the sum of strain energies of pipe segments, joint and soil resistance springs, which are derived separately. By applying the variational principle, the variation of the total potential energy of an equilibrium elastic system is equal to zero; resulting in a governing equilibrium equation:

$$\underset{2n\times 2n}{[K_{system}]}\ \underset{2n\times 1}{\{X\}} = \underset{2n\times 2n}{[K_{soil}]}\ \underset{2n\times 1}{\{X_G\}} \qquad (1)$$

where $[K_{soil}]$, $[K_{system}]$ are the soil resistance and system's structural stiffness matrices; $\{X_G\}$, $\{X\}$ are the ground displacement and the pipeline segments ends displacement vectors respectively.

The quasi-static elasto-plastic analysis uses an energy formulation approach similar to that for the quasi-static elastic analysis, only modifications of energy due to the inelastic behaviors were added.

I.2.3 Method of Solution

Equation [1] can be easily solved, since the equation is basically a static one. Since $\{X_G\}$ is a function of time, the solution of $\{X\}$ is also a function of time. Thus, the method proposed is called the "Quasi-Static" model.

Assuming that the wave form of the traveling seismic excitation remains constant over some length of the pipeline which is divided into n_r-segments, ground motion input remains constant except with some delay time of seismic wave traveling from the first support to the end of the ith pipe segment in the region considered, which can be expressed as,

$$\Delta T_i = \sum_{j=1}^{i} L_j / C_j \qquad (2)$$

where C_j is the traveling wave velocity of the soil surrounding the pipe segment j, L_j is the j^{th} pipe segment length, and n_r is the number of segments in region r. The total time delay will include all the time delays from the beginning of the piping system.

The response of the model displacements, $\{X\}$ are calculated by an interative procedure at each time step for the entire time-history of the earthquake input record. The resulting pipeline nodal displacements, $\{X\}$ are used to determine two pipe design parameters and a soil resistance parameter.

$$\varepsilon_i = (X_{2i} - X_{2i-1})/L_i \qquad (3)$$

$$U_i = X_{2i+1} - X_{2i} \qquad (4)$$

$$Y_i = X_{Gi} - X_{2i} \text{ or } Y_i = X_{Gi} - X_{2i+1} \qquad (5)$$

where

ε_i = average strain in ith pipe segment

U_i = relative displacement, extension/contraction, of ith joint spring between two adjacent pipe segments

Y_i = relative displacement between the ground and the pipe.

I.3 The Investigation Parameters

The model has the capabilities to accept various variable parameters:

- Variable length, cross sectional area of pipe segments;
- Variable joint spring stiffness with joint spring yield possibilities;
- Variable end conditions;
- Variable soil spring constants and with soil strength yield possibilities;
- Variable time delay of traveling waves;
- Variable wave form (up to four).

The major independent investigative parameter in this study is the joint stiffness. It varies from very soft spring (10^0 kips/in), to very stiff spring (10^9 kips/in). Even though this model is for a segmented piping system, it can also be used to model a continuous piping system by specifying very stiff joint spring (ie. 10^9 kips/in or higher). Other investigative parameters are presented below.

I.4 The Reference Piping System

To establish a basis for comparison of the seismic response behavior of buried pipelines for various parameters, the following conditions to give elastic responses are arbitrarily chosen as the "reference" conditions:

Pipeline Parameters

Material (steel)	$E = 30{,}000$ ksi
External Diameter	$DE = 18$ ins
Internal Diameter	$DI = 17.5$ ins
Number of Segments	$n = 20$
Segment Length	$L_i = 20$ ft
Free End Condition	$K_0,\ K_{n+1} = 0.0$
Fixed End Condition	$K_0,\ K_{n+1} = 10^9$ kips/in

Soil Parameters

Wave Propagation Velocity	$C = 3960$ in/sec
Soil Stiffness	$k_i = 565$ kip/in/in

Seismic Parameters

El Centro May 18, 1940	S90W component
Maximum Ground Displacements	$\Delta_{max} = 7.8$ in
Duration	$T = 53.6$ sec
Maximum Velocity	$V_{max} = 14.5$ in/sec

For an evaluation of the effects of a particular parameter upon the response behavior, only that parameter will be varied from the above mentioned reference conditions.

I.5 Summary and Discussions

To prove the correctness of the formulation, several tests and comparisons with other models have been made by Serna (4). The results indicate differences of between 1% to 3%.

The analysis takes into account, elasticity of pipe material, joint stiffness, and soil resistance characteristics. The computer program that was developed based on this analysis is discussed in details in part III of this report.

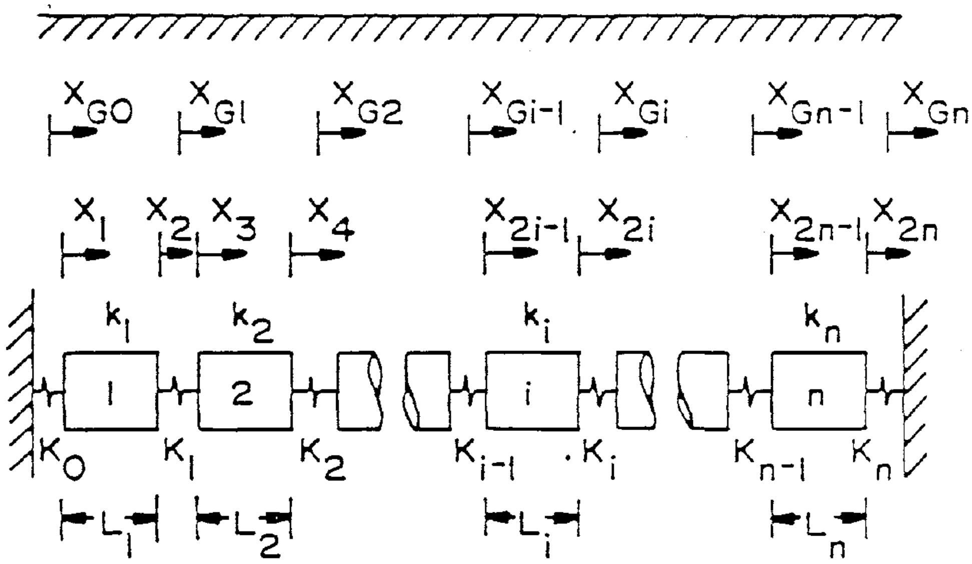

FIG. I.1 QUASI-STATIC ELASTIC SEISMIC ANALYSIS MODEL FOR BURIED PIPELINE.

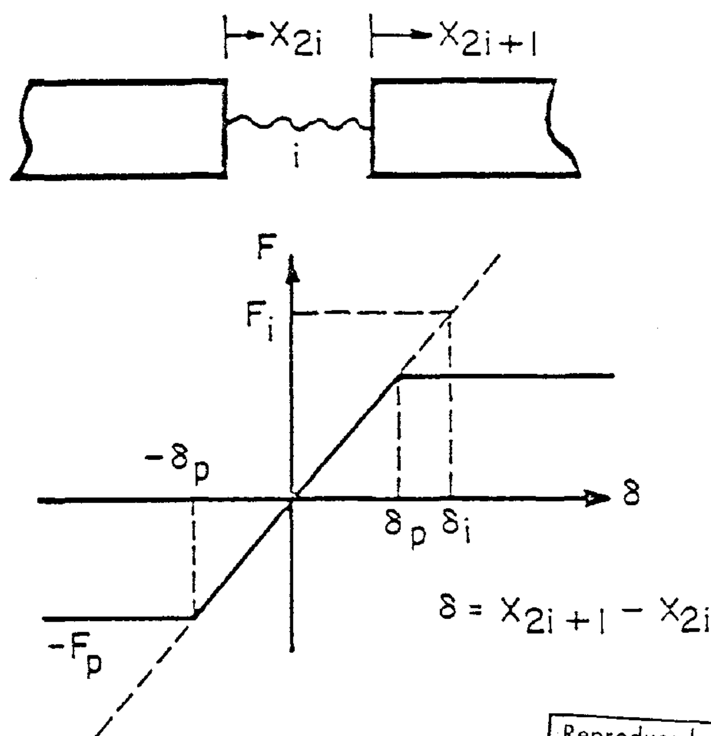

FIG. I.2 i^{th} ELASTO-PLASTIC JOINT SPRING AND ITS RESISTANCE CURVE

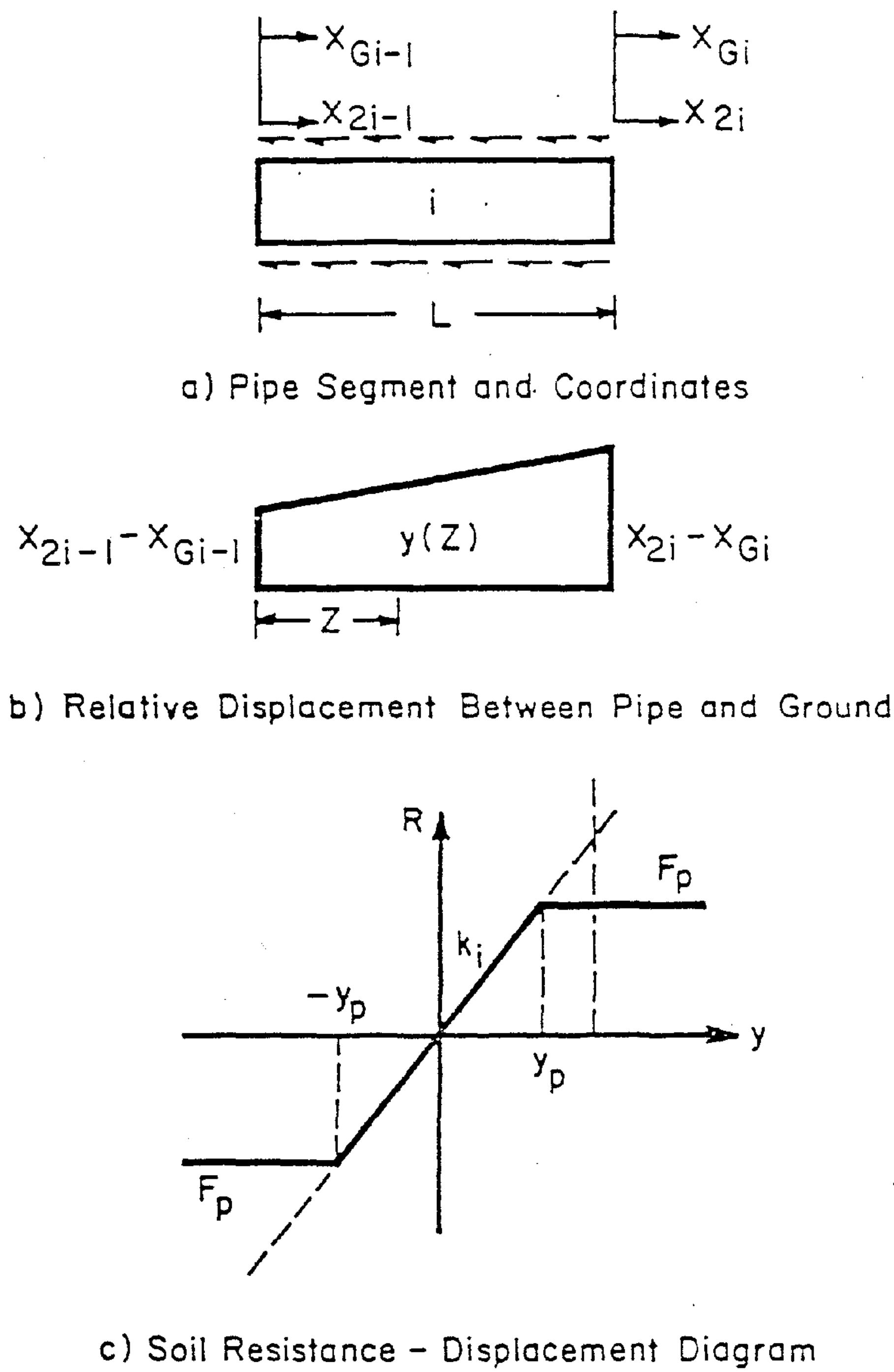

FIG.I.3 ELASTO-PLASTIC SOIL RESISTANCE-DISPLACEMENT CHARACTERISTICS OVER A PIPE SEGMENT

PART II

PARAMETRIC RESPONSE OF BURIED PIPELINES

II.1 Preface

The quasi-static elasto-plastic analysis model was briefly discussed in part I of this report. And all the reference parameters were given Section I.4. The computer program that was developed based on this analysis is given in Appendix A and will be discussed in Part III of this report. A sample run including the input and output files print-outs are given in Appendix B.

The pipeline is assumed to be straight and of prismatic cross section. The pipe joints and soil springs are linear elastic material with the possibility of becoming plastic as shown in Figures I.2 and I.3.

II.2 Time History Ground motion input and Pipeline responses

In this part of the report, the results of the effects of various parameters on the response behaviours of buried pipeline system using the computer program and the El. Centro, 1940,earthquake record are presented. The El. Centro earthquake ground displacements were recorded at 0.1 second time interval; the displacement time history is shown on Table II.1 and the graphical plot is shown on Figure II.1. The induced ground displacements along the pipe nodes for several instances are shown in Fig. II.2.

In order to observe the effects of end conditions on the responses, the responses at times 2.3 and 12.9 seconds were obtained, using the El. Centro earthquake and all the reference conditions in Section I.4. The results are shown on Fugures II.3 and II.4 respectively. Only minor differences are observed at the ends of the pipelines, where the fixed end pipeline shows higher responses.

II.3 Effect of Plasticity of joints and/or soil

The results of the effect of joint stiffness on the maximum pipe strains, maximum relative joint displacement and max. relative displacement between the joint and soil are shown of Figures II.5 and II.6 respectively. They represent the responses under elastic condition of both the joints and the surrounding soil, which will be used as reference responses to compare with those when the joints and/or the surrounding soil is made plastic.

It can be seen from these figures that the responses remain the same as joint stiffness increases up to 1,000 ksi, and as joint stiffness increases beyond 1,000 ksi, pipe strain increases. At very high joint stiffness (approaching continuous pipe), pipe strains approaches its upper bound limit. The results also show joint displacement decreasing as joint stiffness increases beyond 10,000 ksi, and for very high joint stiffnesses, joint displacements reduces to almost zero.

Figures II.7 and II.8 show the effects of ultimate joint resistance on the responses, for a varying stiffness of the joints. The joints are made plastic by specifying maximum elastic (yield) displacements (δ_J) varying from 0.001 inch to 0.5 inch. A specified maximum elastic displacement of 0.5 inch is very much closer to the elastic condition than that of a specified maximum elastic displacement of 0.001 inch. In fact, the responses for δ_J = 0.5 inch is only slightly different from the responses for the elastic conditions. One can see from these Figures that, pipe strains become smaller as δ_J becomes smaller (joints have lower plastic strength). For high joint stiffness, pipe strain approaches the same upper bound limit as a continuous pipe. Figure II.8a shows the effect on relative joint displacements to increase as δ_J is decreased for high joint stiffness. And for lower joint stiffness, relative joint displacements remain constant approaching the upper bound limit.

The responses under plastic condition of the surrounding soil is then investigated. The soil is made plastic by specifying maximum elastic (yield) displacement (δ_S) varying from 0.001 in. to 0.5 inch, while the joints remain elastic. The results are shown in Figures II.9 and II.10. The results obtained with a specified δ_S = 0.5 (i.e. approach elastic condition) is very close to the results for the elastic condition. From these figures, it is obvious that as the specified maximum soil yield displacement (δ_S) decreases, pipe strains and other responses become appreciably smaller and joint displacements also become lower.

The results for the plastic conditions of both the joints and soil are shown in Figures II.11 and II.12. This represents the combined effect of plastic conditions of both the joints and soil, hence the result is mixed, but the responses are much lower than that of in the elastic condition, with the lower bound approaching to that of plastic soil condition.

Conclusions

1. From the results of this part it can be concluded that less damage is done to the pipes (lower pipe strains) as the joints and/or soil become plastic.
2. The plastic soil condition is more influencial in reducing pipe strains than the plastic condition of the joints,
3. Joint displacement increases under plastic condition of the joints, but decreases under plastic condition of the surrounding soil.

II.4 Effect of Soil and Geological Conditions

The difference in the responses for a fixed-fixed end and a free-free end pipeline is at the end pipes/joints, as verified in Figures II.3and II.4. The fixed-fixed end pipeline experiences more damages (pipe strains and joint movements), with the maximum effects at or near the ends, than the free-free end pipeline; while the responses in the interior pipes/joints are the same for both end conditions. In this investigation, we observe the effect of abrupt changes of soil and geological condition on the response of buried pipeline, using different end conditions for comparison.

A list of all the reference conditions is given in section I.4. In this section, the surrounding soil is assumed to consist of two regions of varying soil stiffnesses and wave propagation velocities. The first half of the pipeline (pipes No. 1 to 10) is assumed to lie in the first region (referred to as region 1) and the second half of the pipeline (pipes No. 11 to 20) in the second region (referred to as region 2). The variations are obtained by taking a ratio of the reference condition, for example, $\frac{V_1}{V_2} = \frac{1}{2}$ implies that the wave propagation velocity in region 1 (V_1) is 3,960 in./sec. (reference condition), and wave propagation velocity in region 2 (V_2) is 7,920 in./sec., all other reference conditions remain the same.

The end joint stiffness equals zero for a free end condition, and 10^9 ksi for fixed end condition are used. The results of the responses for a particular parameter are plotted on the same page for comparisons.

II.4.1 Effect of Soil Stiffness

Results

This section of the investigation focuses on the responses under abrupt changes in soil stiffness, i.e. $\frac{K_1}{K_2} = \frac{1}{1}, \frac{1}{2}, \frac{1}{5}$ etc. all other reference conditions remain the same. Figure II.13 shows the effect of soil stiffness changes on pipe strains (free-free ends); here it is obvious that as the soil stiffness increases (in either region) pipe strain increases. It is also observed that for higher joint stiffnesses (beyond 1,000 ksi), pipe strain increases and tends to approach the same upper bound. The results show that, the maximum pipe strain is governed by the region of higher soil stiffness, where it also occurs.

As shown in Figure II.14, for $\frac{K_1}{K_2} = \frac{1}{1}, \frac{1}{2}, \frac{1}{5}, \frac{1}{10}$, the joint movement is governed by the region of lower soil stiffness where the maximum joint displacements occur. There is no difference in maximum relative joint displacement within a pipeline.

The results with the fixed-fixed end are shown in Figures II.15 and II.16. The results are similar to those obtained with the free-free ends except that the responses (pipe strains and joint displacements) are higher with the ends fixed. As with the free-

free ends, maximum pipe strains occur in the region of higher soil stiffness. The maximum pipe strain occurs in the end pipes and for uniform soil stiffness, it occurs at both end pipes. Joint displacements are governed by the softer soil (lower stiffness) and occurs in the softer soil. And joint displacements become lower for higher (beyond 1,000 ksi) joint stiffnesses.

The results with the fixed-free ends (first end joint fixed, last end joint free) are shown in Figure II.17. The results represent the combined effects of end condition and soil stiffness, hence, the response is mixed. Since stiffer soil/end fixity tends to increase the responses, maximum responses will be governed by which effect governs the responses as the joints stiffnesses increase.

Conclusions

From the investigations of this section some concluding remarks can be made as follows:

1. Pipe strain increases as soil stiffness and joint stiffness increase.
2. The pipeline with fixed ends shows relatively higher responses (pipe strains/joint displacements) than with free ends, and the maximum responses occur in the pipes/joints at or near the fixed ends.
3. Maximum joint displacements occur in the softer soil (lower soil stiffness) and decreases as soil stiffness becomes higher.

II.4.2 Effect of Wave Propagation Velocity

Results

The results of the investigation on the responses of buried pipeline under abrupt changes of wave propagation velocity (geological changes) are presented in this section. Figure II.18 shows the effect of wave propagation velocity (V) changes on pipe strains for the free-free end condition. It is observed that pipe strains are the same for $\frac{V_1}{V_2} = \frac{1}{1}, \frac{1}{2}, \frac{1}{5}, \frac{1}{10}$, which implies that pipe strain is governed by the soil region with lower wave propagation velocity. Relative joint displacement is also governed by the soil region with lower wave propagation velocity (Fig. II.19). Pipe strains/joint displacements reduces as wave propagation velocity is increased. The results of fixed-fixed end condition as shown in Fig. II.20 & II.21 shows higher responses (pipe strains/joint displacement) than that of the free-free end condition. The results for the fixed-free end condition are also shown in Fig. II.22, which represents the combined effect of end conditions and wave propagation velocity.

Conclusions

1. Pipe strains decreases as wave propagation velocity increases.
2. The responses (pipe strains/joint displacements) are governed by the soil region with lower wave propagation velocity, where the maximum response also occurs.
3. The pipeline with fixed ends shows relatively higher responses (pipe strains/joint displacements) than with

free ends, and the maximum response occurs in the pipes/joints at or near the ends.

II.5 Effect of Seismological Condition

In all of the above investigations, the El Centro, 1940, earthquake record was used. The earthquake data consists of 536 records at 0.1 seconds time interval of record. The data was recorded at one location, and for the above investigations, all other locations along the pipe line are assumed to have the same earthquake record (constant wave form) except with some time delay incorporated. The delay time depends on the distance from the assumed point of record and the wave propagation velocity. In actual earthquake, seismic changes that take place makes this assumption to be untrue. In this part of the report we present some of the results obtained in an effort to evaluate the effect of seismic changes on buried pipeline, using the El Centro earthquake records as reference data.

A pipeline model, consisting of 22 pipe joints is divided into two regions with joints 1 to 11 in region I and joints 11 to 22 in region II. The ground movements (at joints) in region II is subjected to variations from the reference data. One variation of the earthquake wave form is that a 5% or 10% decrease/increase in the magnitude of the original reference ground movement record for region II. Another variation of earthquake wave form is done by given a time delay, say 0.5 second or 1.0 second to the original ground movement data of region I for region II. The third variation is that the ground movement of region II is the same in magnitude but reverse in sign as that of of the original record for region I.

Results

The results of this section are not very conclusive, in that, the responses (pipe strains/joint displacements) depends on the original reference earthquake records. Figures II.23 and II.24 show the results obtained using the El-Centro earthquake, between time = 2.3 seconds and 13.0 seconds, as reference. The responses (pipe strains/joint displacements) are higher for amplification and lower for reduction; but the variations are very small. One can see that for this earthquake, the responses become higher with an increase in the delay time. The reverse waveform for the two regions give the highest responses.

Conclusions

1. It can be concluded generally that amplification/reduction of ground movements increases/reduces the responses (pipe strains/joint movements) respectively.
2. The maximum response (maximum pipe strain/maximum joint displacement) occurs in the pipe/joint at or near mid-pipeline where the abrupt seismological changes occur.

II.6 Summary and Discussions

The results of the response behavior of buried pipelines under seismic excitation in the axial direction with changes in various physical, geo-technical and seismological parameters are presented in this part of the report.

The physical parameters investigated are the plastic condition of the joints and the surrounding soil. The geo-technical parameters investigated are the stiffness of the surrounding soil and the velocity of wave propagation. And the seismological parameter investigated is the effect of wave form changes, such as amplifications, abrupt wave travel delay, etc.

Some conclusions have been made based on the results and were presented at the end of each section. We now summarize all the conclusions and try to explain the reasons for some of the results as follows:

. Less damage is done to the pipes (lower pipe strain) as the joints or the surrounding soil become plastic. But the plastic condition of the soil is more influential in lowering pipe strain than the plastic condition of the joints.

. Joint movements increases under plastic condition of the joints, but decreases under plastic condition of the surrounding soil.

. Pipe strain increases as the surrounding soil stiffness increases.

. The pipeline with the ends fixed shows relatively higher responses (pipe strains/joint movements) than the same pipe-pipeline with the ends free.

. The responses are higher as wave propagation velocity is decreased for the entire pipeline. In the case of different wave propagation velocity along the pipeline, the responses are governed by the soil region with lowest wave propagation velocity.

. It can be concluded that amplification/reduction of the ground movements increases/decreases the responses, respectively, but the increase/decrease are only very slight.

. Even though the responses for a fixed end condition are relatively higher than the responses for a free end condition, the differences in the responses are only observed in the end pipes/joints. The responses for the interior pipes/joints are the same for both end conditions.

Table II.1 El-Centro Earthquake Displacement

Time History, S90W, May 18, 1940

0.531496	1.015354	1.518503	2.052755	2.630709	3.223228	3.826772	4.464566
5.120472	5.623622	5.927559	6.030708	6.018503	6.059448	5.922441	5.361417
4.422834	3.522834	3.056692	2.981889	2.245275	1.074409	-0.333465	-1.576771
-2.945275	-4.094094	-5.179133	-6.249212	-7.113382	-7.661810	-7.788584	-7.684644
-7.340552	-6.936615	-6.379922	-5.620866	-4.779921	-4.260236	-3.933858	-3.726771
-3.629921	-3.574016	-3.527558	-3.652362	-3.468897	-2.984645	-2.498818	-2.454723
-2.712204	-2.801181	-2.637008	-2.305905	-1.877953	-1.280708	-0.412205	0.344094
0.822835	1.340550	1.785039	2.062598	2.295669	2.484252	2.723621	2.966928
3.181102	3.279921	3.434646	3.600787	3.757087	3.867716	3.824409	3.921260
3.830315	3.587795	3.574409	3.659055	3.590944	3.414567	3.348818	3.302755
3.136614	2.749999	2.159842	1.475984	0.764961	-0.195276	-1.087794	-1.638582
-2.118110	-2.599213	-2.932283	-2.926771	-2.611417	-2.124803	-1.568503	-1.087794
-0.795669	-0.572047	-0.503150	-0.431496	-0.303150	-0.400394	-0.563780	-0.584252
-0.531496	-0.520079	-0.583071	-0.740157	-0.884646	-0.962992	-1.013386	-0.909055
-1.024015	-1.485039	-1.902362	-1.696850	-0.853937	0.226772	0.974016	1.675590
1.998031	1.993306	1.702755	1.266929	0.995276	0.806693	0.542520	0.278346
0.099606	0.081102	0.086614	0.037795	0.033858	-0.033465	-0.121653	-0.303937
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-1.317717	-1.307086	-1.364566	-1.409449	-1.451968	-1.636614	-1.838976	-1.924409
-2.088976	-2.273622	-2.371260	-2.348425	-2.214172	-2.021653	-1.771259	-1.342519
-0.899606	-0.594094	-0.272441	0.199213	0.650394	0.987402	1.378739	1.809842
2.112598	2.273622	2.371260	2.486613	2.609055	2.690945	2.724015	2.743307
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2.103149	2.129921	2.111417	2.146456	2.370078	2.495275	2.423622	2.353936
2.212204	1.962992	1.697638	1.569685	1.557874	1.427559	1.167322	1.053937
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1.048819	0.979134	1.042126	1.048819	1.085039	1.200000	1.177559	1.011810
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-1.325590	-1.449212	-1.661811	-1.770079	-1.995669	-2.198818	-2.446456	-2.760236
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-5.103936	-5.198818	-5.184645	-5.356298	-5.499212	-5.633858	-5.784252	-5.711023
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-4.565353	-3.844488	-3.239763	-2.564960	-1.681496	-0.939764	-0.293307	0.092520
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3.669291	3.399212	3.131495	2.822834	2.568897	2.312204	2.049031	1.807480
1.511417	1.458661	1.437401	1.448424	1.411811	1.321653	1.296456	1.375196
1.442913	1.417716	1.381889	1.379346	1.336614	1.184645	1.048425	0.983465
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0.654331	0.647638	0.648031	0.617717	0.605512	0.568897	0.505512	0.455512
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-1.698424	-1.721259	-1.781495	-1.876771	-2.012992	-2.190157	-2.348818	-2.470078
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0.116929	0.289764	0.429527	0.520079	0.562598	0.546063	0.503937	0.464567
0.410630	0.353543	0.318110	0.308661	0.320472	0.354331	0.416535	0.494094
0.545669	0.575984	0.616535	0.683071	0.751575	0.805905	0.881496	0.994882
1.147637	1.352362	1.594094	1.850787	2.112205	2.371260	2.627559	2.865747
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3.923621	3.941731	3.926771	3.888976	3.825590	3.725984	3.634252	3.549212
3.453543	3.340550	3.196457	3.016535	2.775590	2.472441	2.139370	1.811024
1.479134	1.127559	0.770472	0.434252	0.129921	-0.140945	-0.403543	-0.671260
-0.956299	-1.240551	-1.522440	-1.800393	-2.061023	-2.298819	-2.519685	-2.709449
-2.862992	-2.972047	-3.042126	-3.074016	-3.070079	-3.038976	-3.000393	-2.970078
-2.922441	-2.814960	-2.661417	-2.480708	-2.289370	-2.090551	-1.904330	-1.748031
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-0.521654	-0.531102	-0.440157	-0.360630	-0.298425	-0.242913	-0.198425	-0.156299
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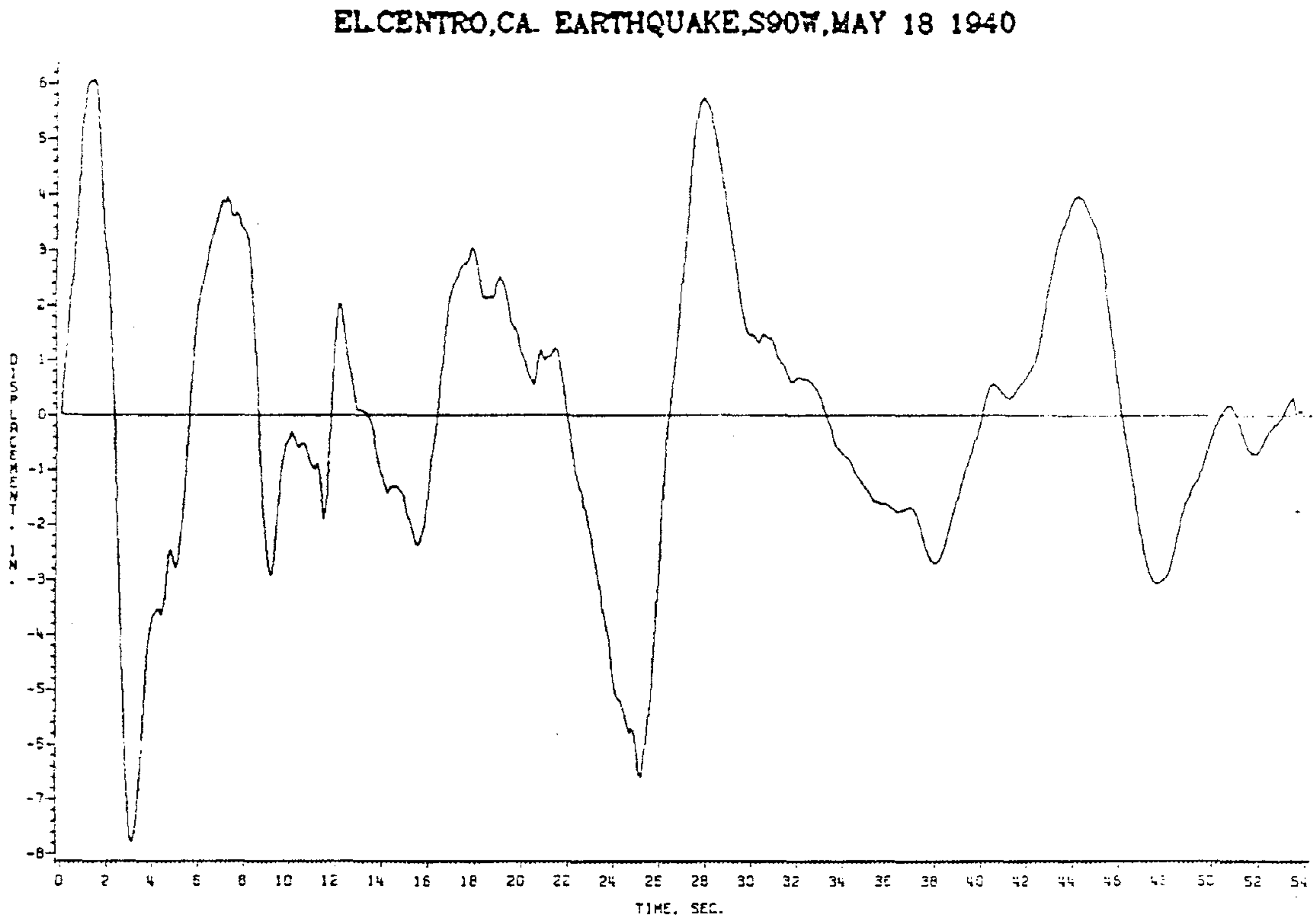


Figure II.1 Reference Ground Movement Input

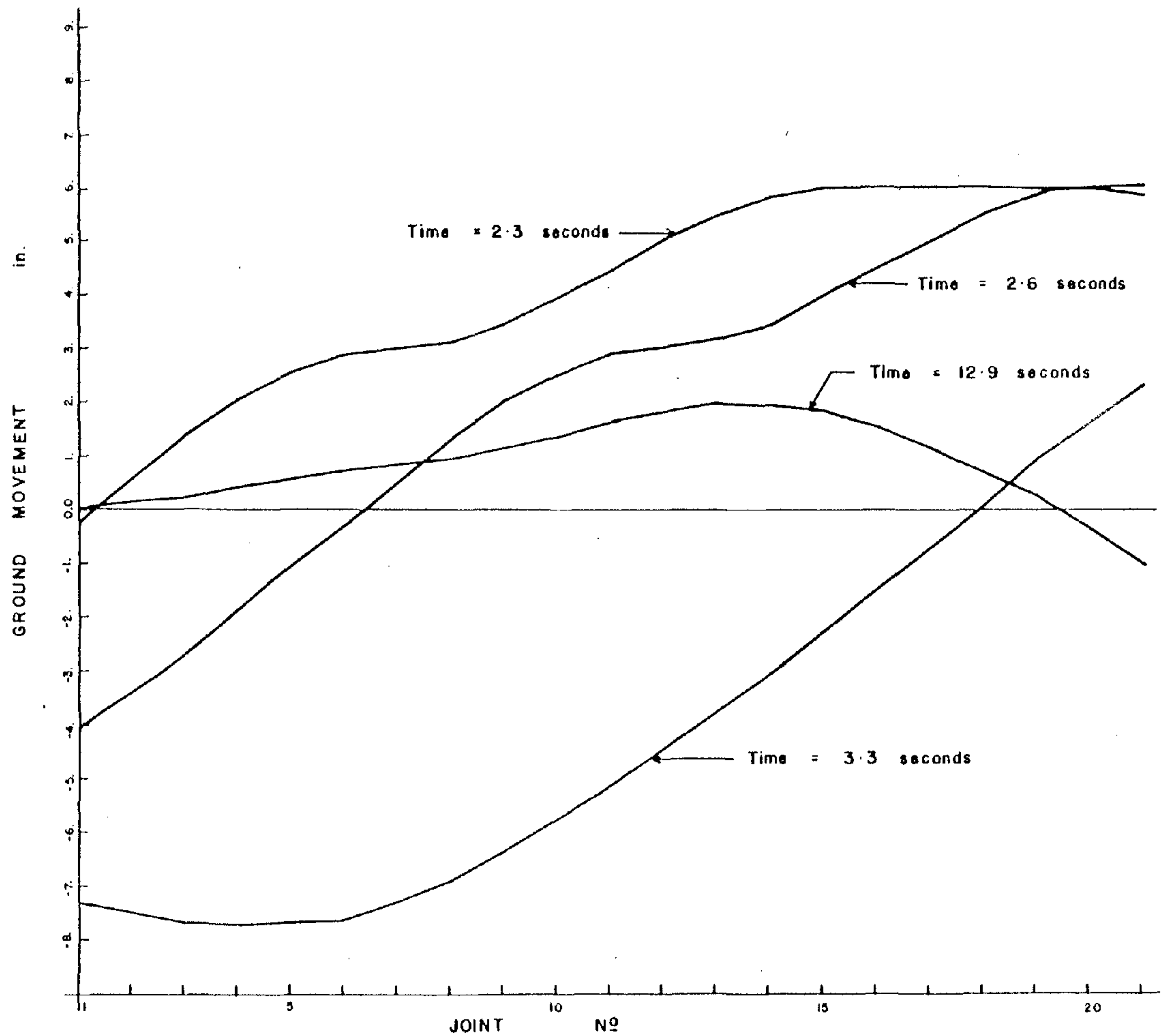


Figure II.2 Ground Displacement at Various Times

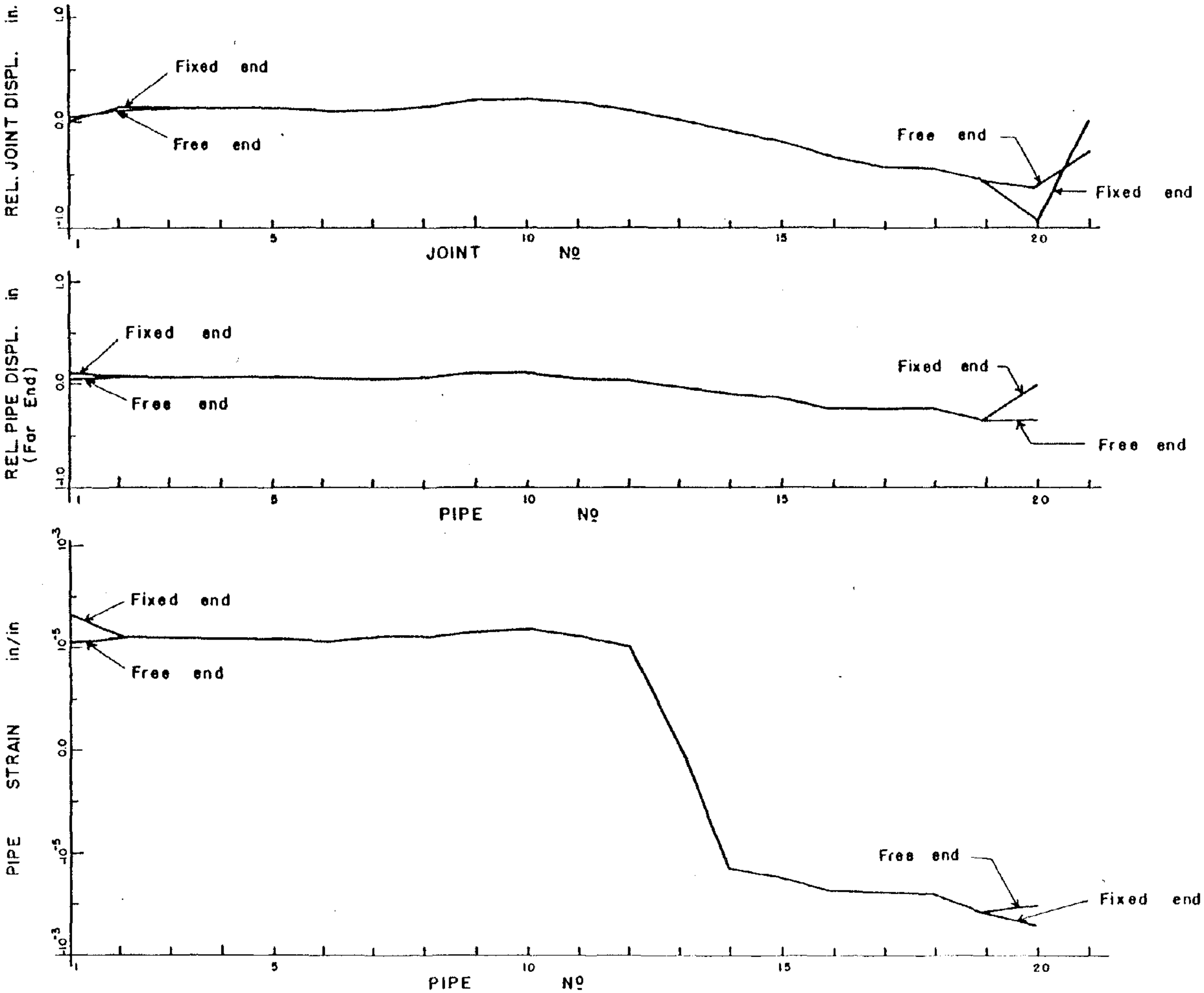


Figure II.3 Responses at time = 2.3 Seconds

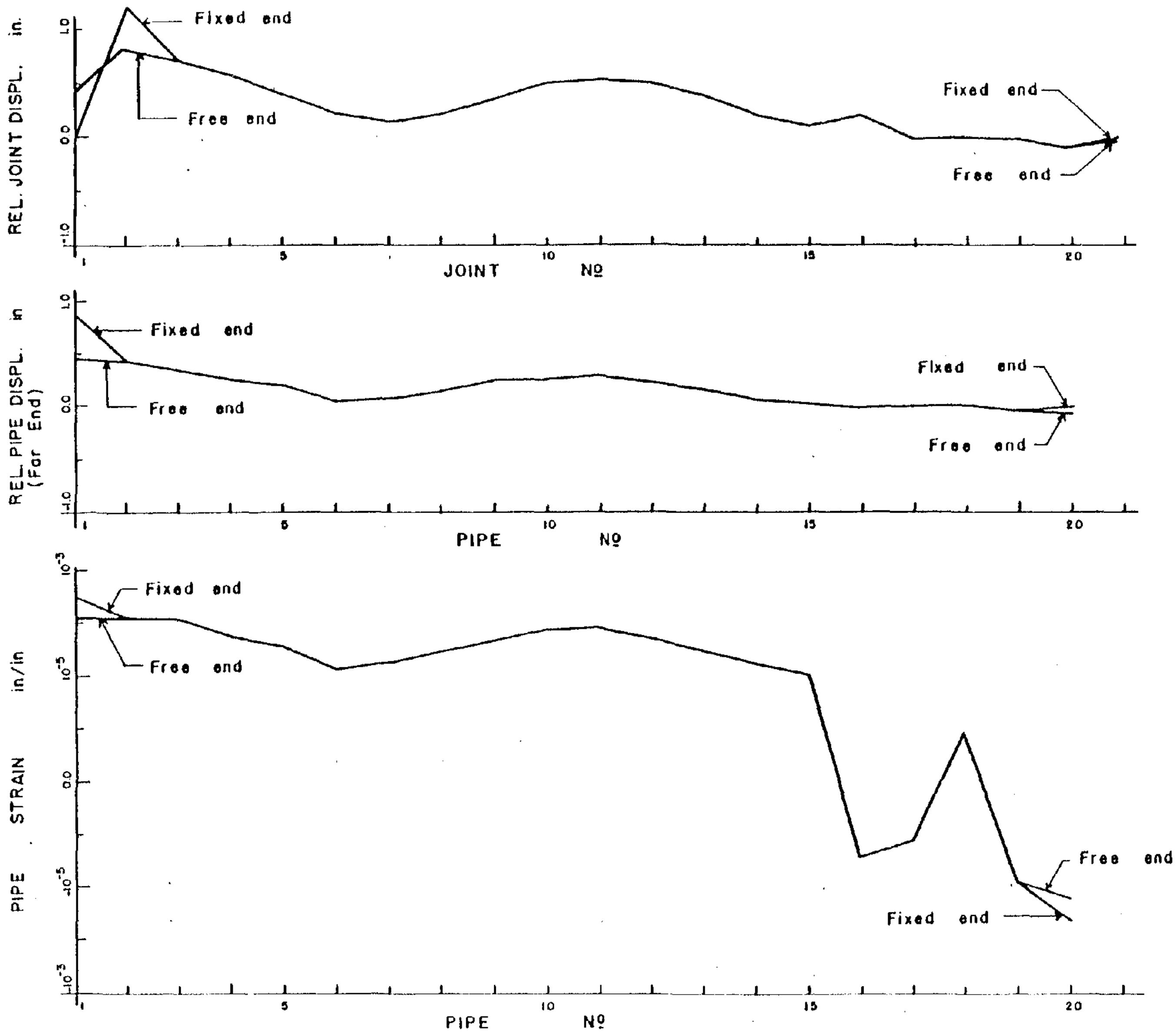
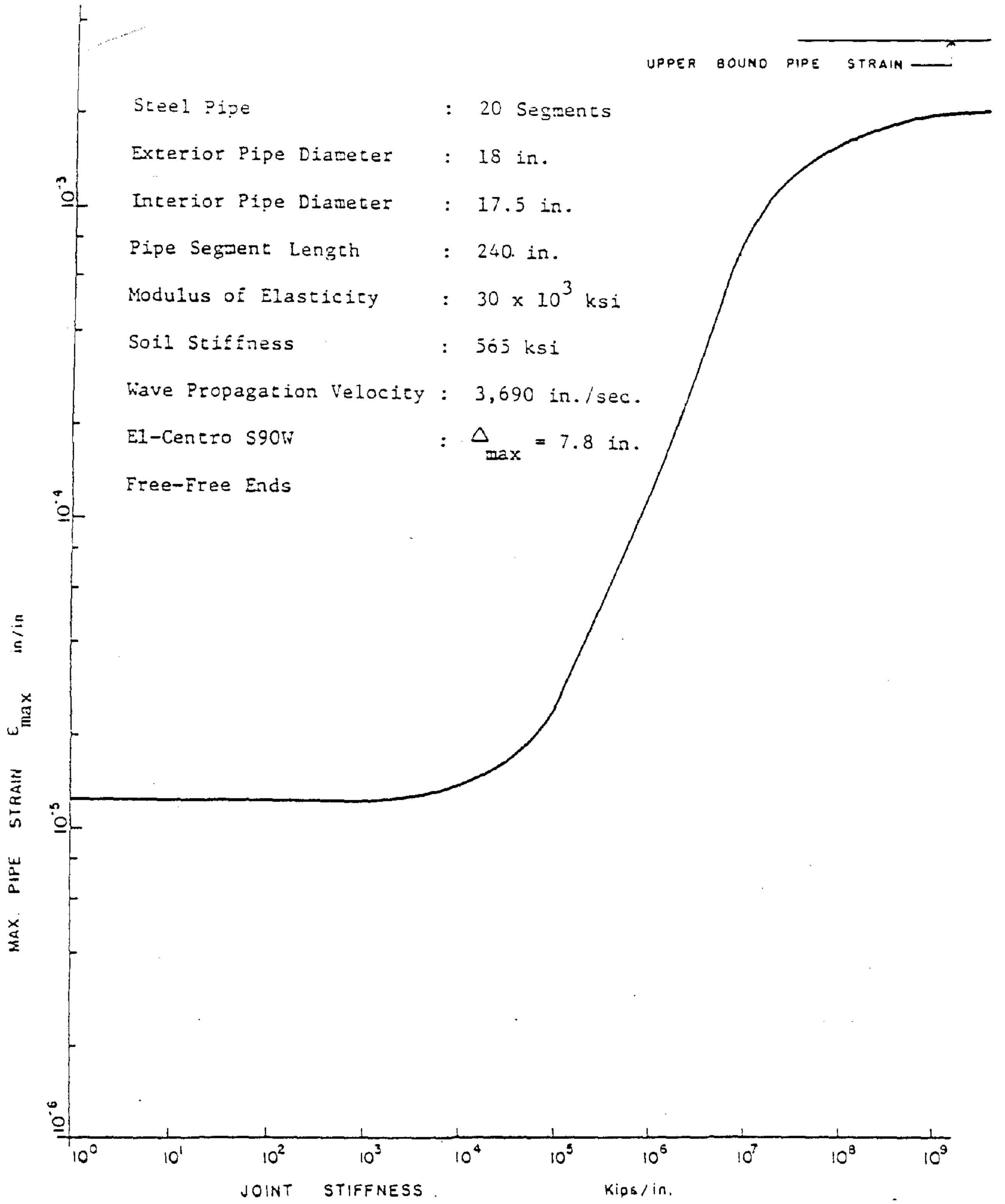
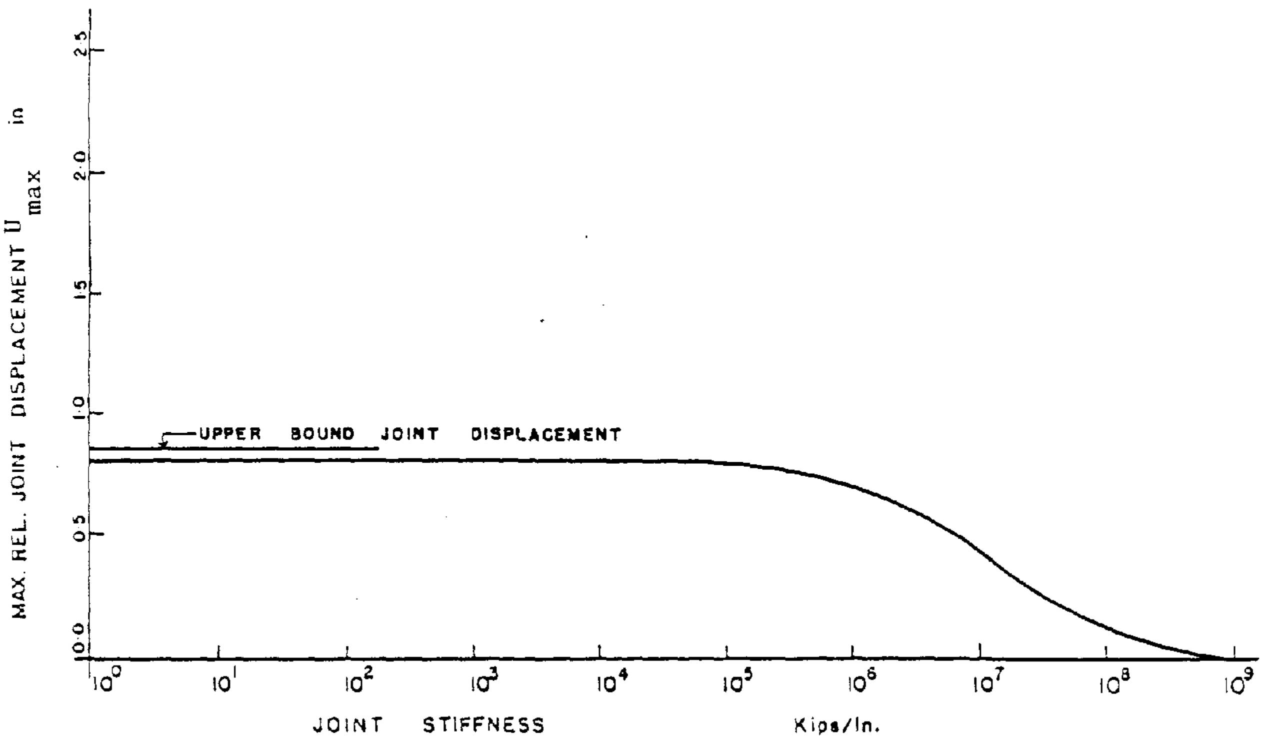


Figure II.4 Responses at time = 12.9 Seconds

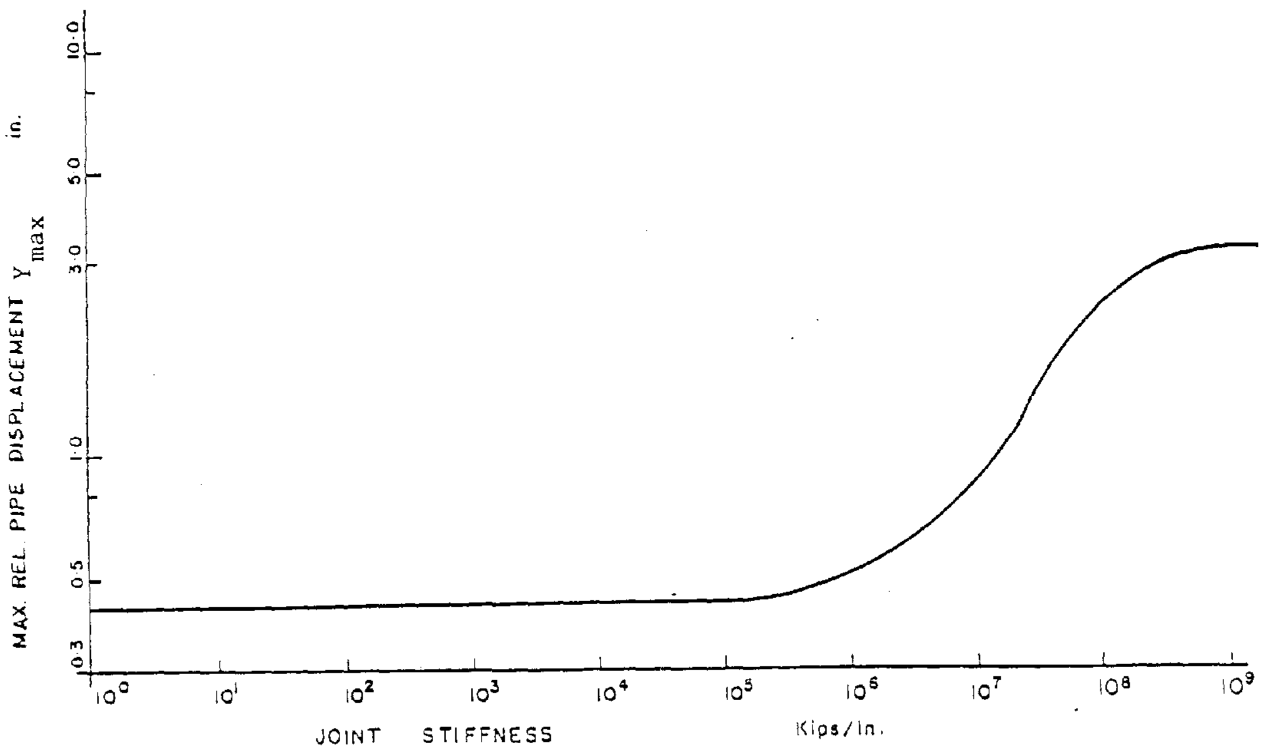


Effect of Joint Stiffness on Pipe Strains
(Joint Elastic, Soil Elastic)

Figure II.5

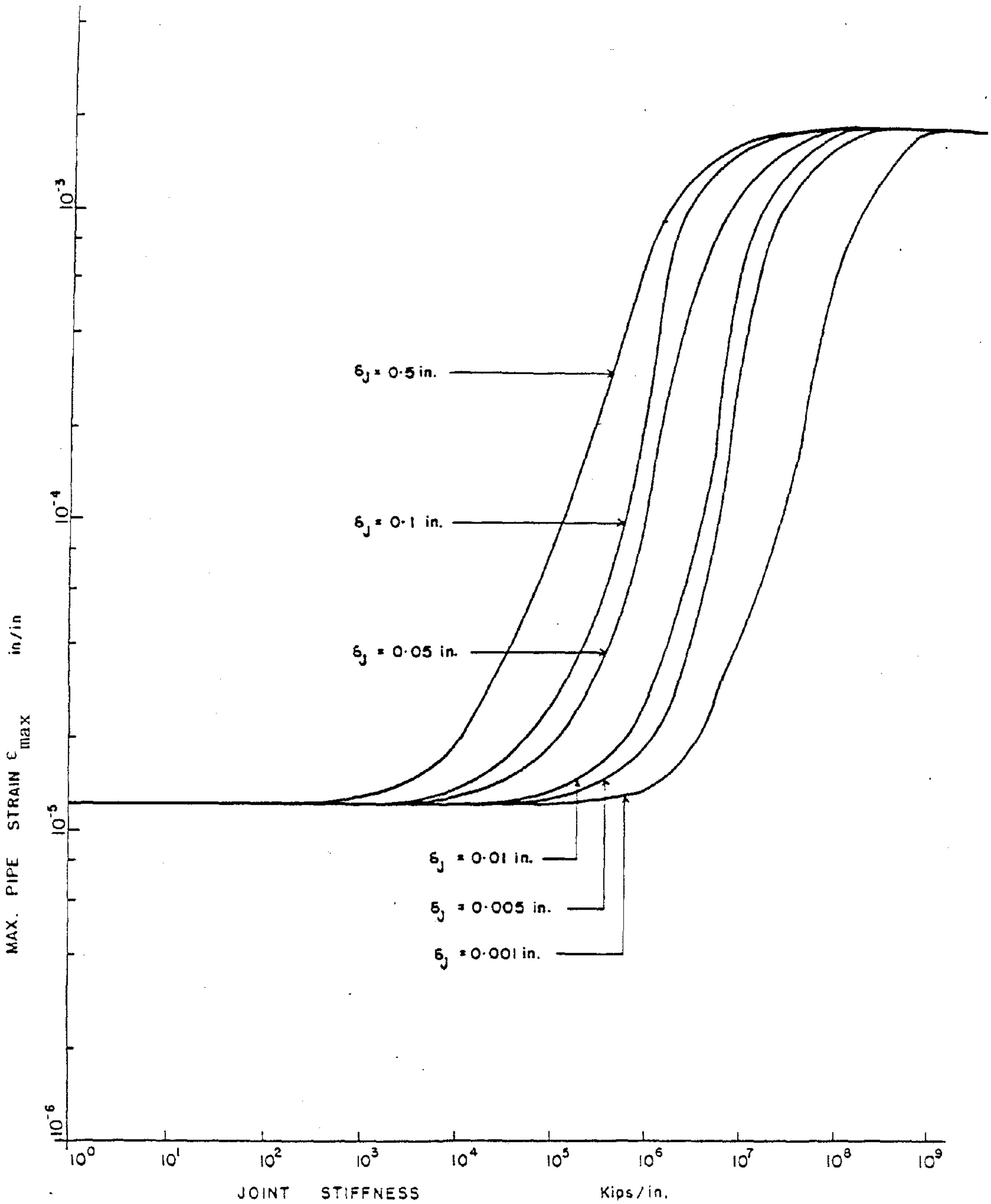


(a) Effect of Joint Stiffness on Relative Joint Displacements
(Joint Elastic, Soil Elastic)



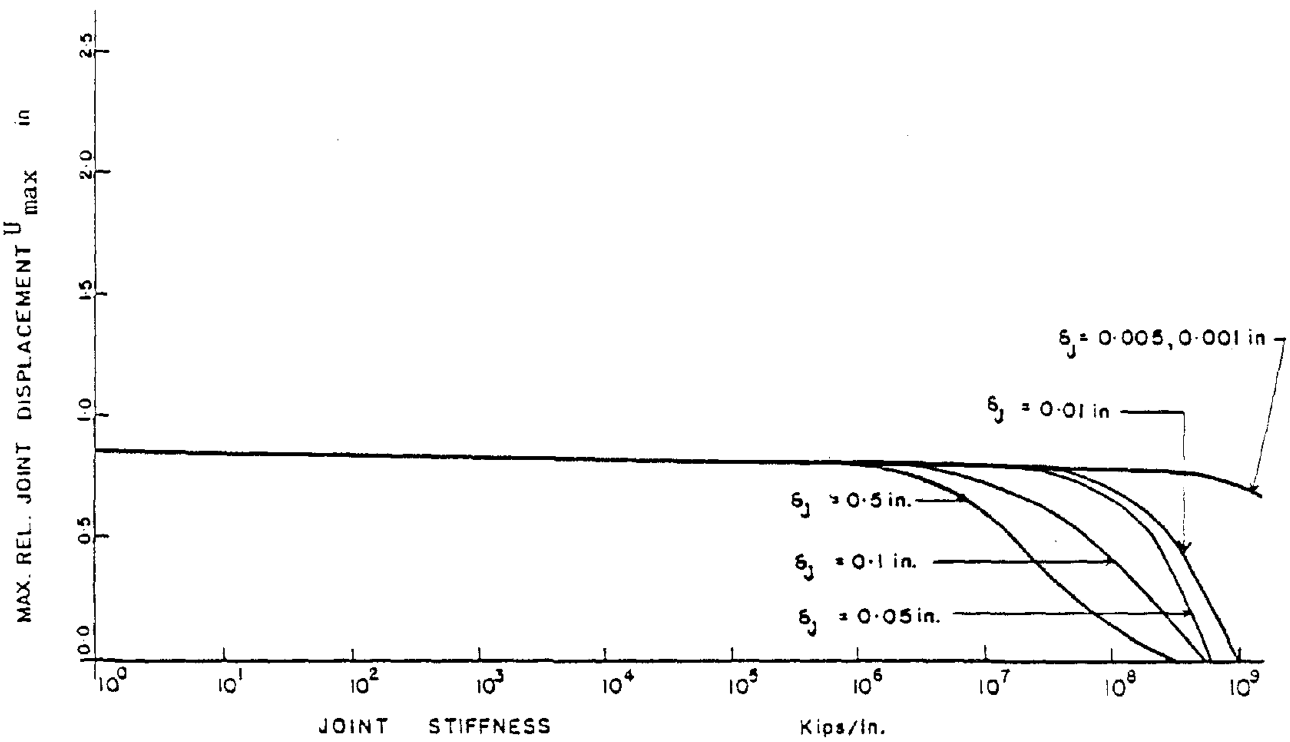
(b) Effect of Joint Stiffness on Relative Pipe Displacements
(Joint Elastic, Soil Elastic)

Figure II.6

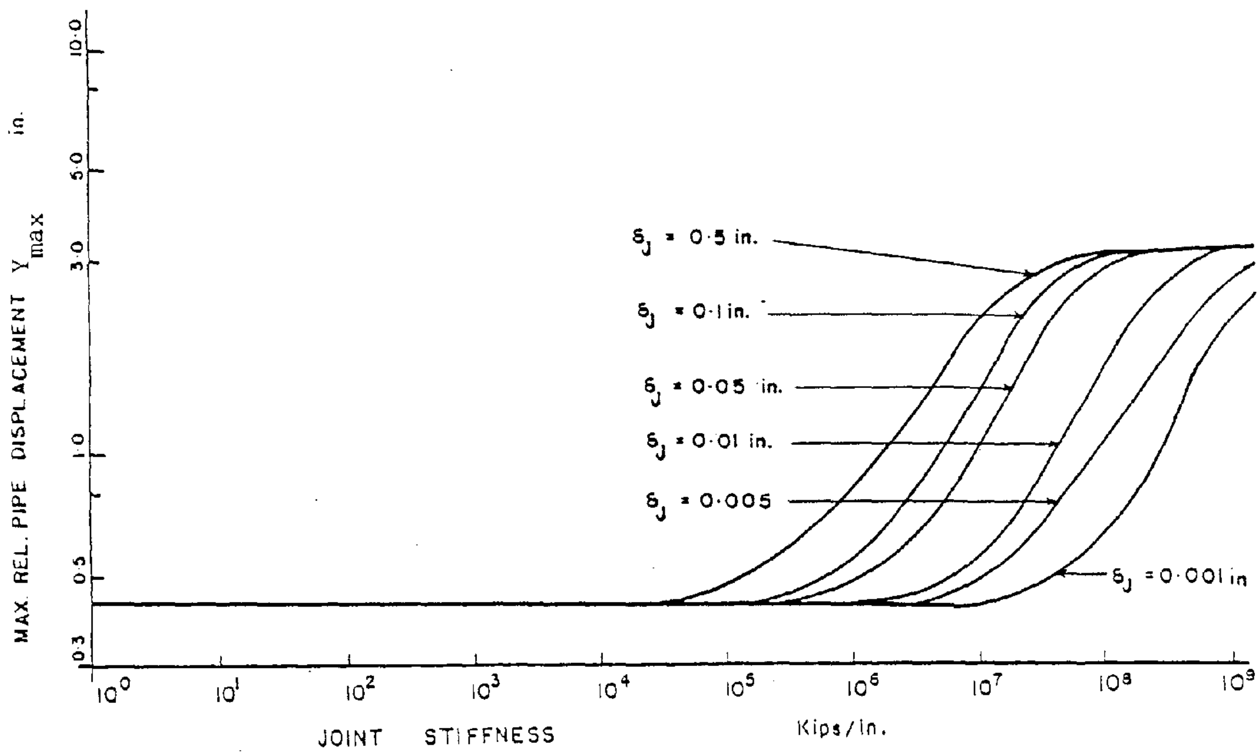


Effect of Joint Stiffness on Pipe Strains
(Joint Inelastic, Soil Elastic

Figure II.7

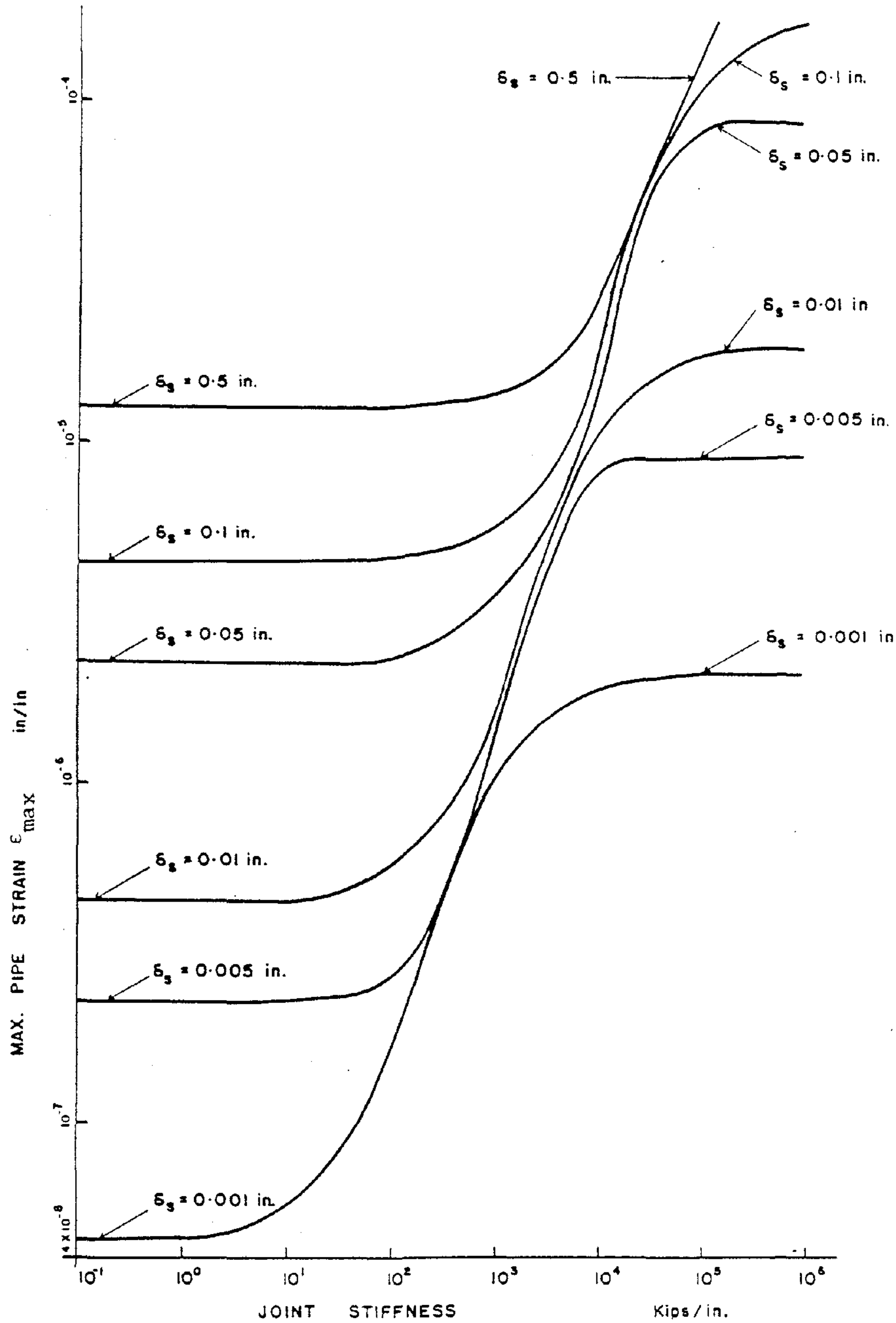


(a) Effect of Joint Stiffness on Relative Joint Displacements
(Joint Inelastic, Soil Elastic)



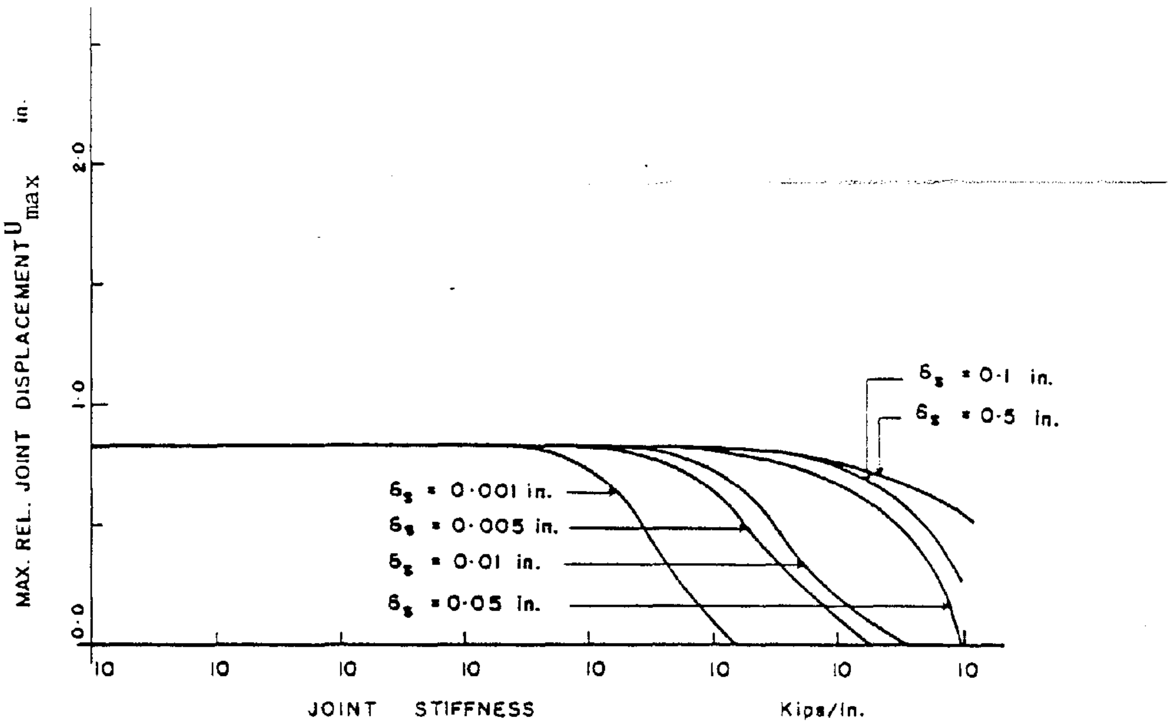
(b) Effect of Joint Stiffness on Relative Pipe Displacements
(Joint Inelastic, Soil Elastic)

Figure II.8

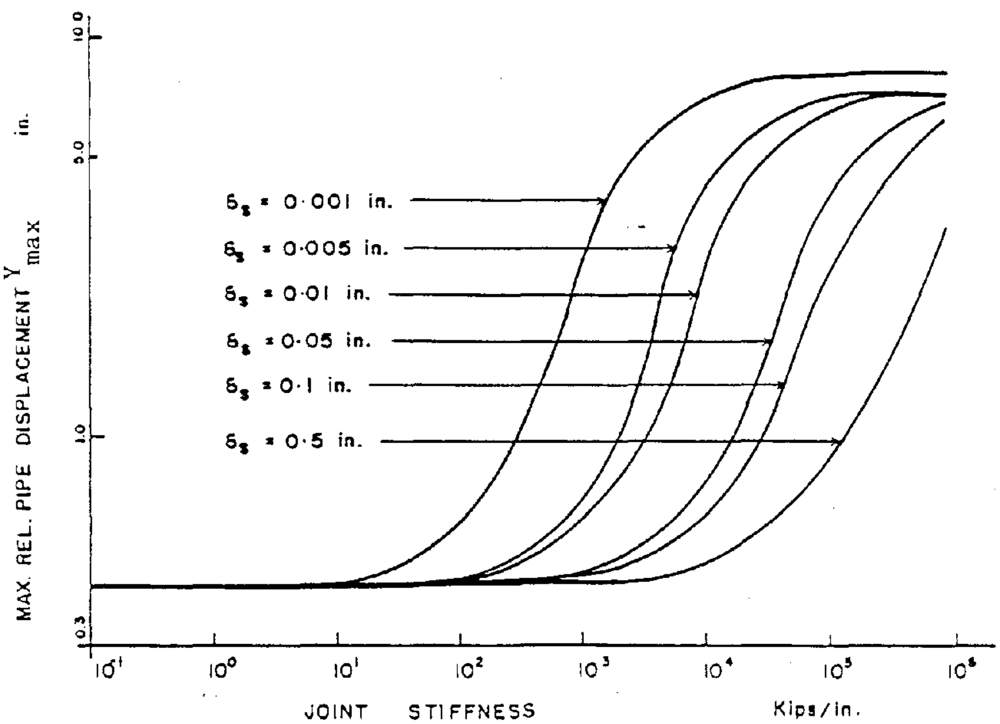


Effect of Joint Stiffness on Pipe Strains
(Joint Elastic, Soil Inelastic)

Figure II.9

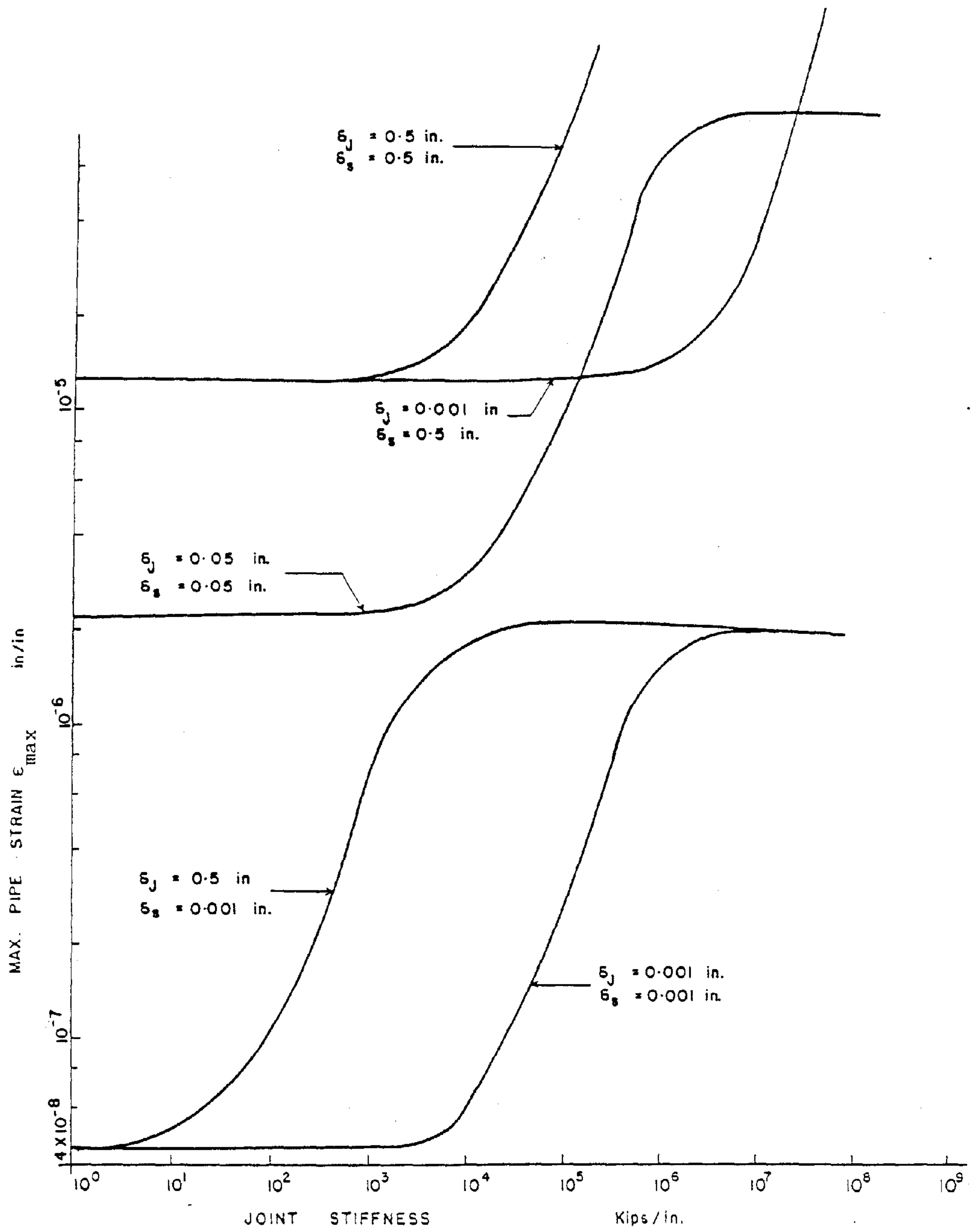


(a) Effect of Joint Stiffness on Relative Joint Displacements (Joint Elastic, Soil Inelastic)



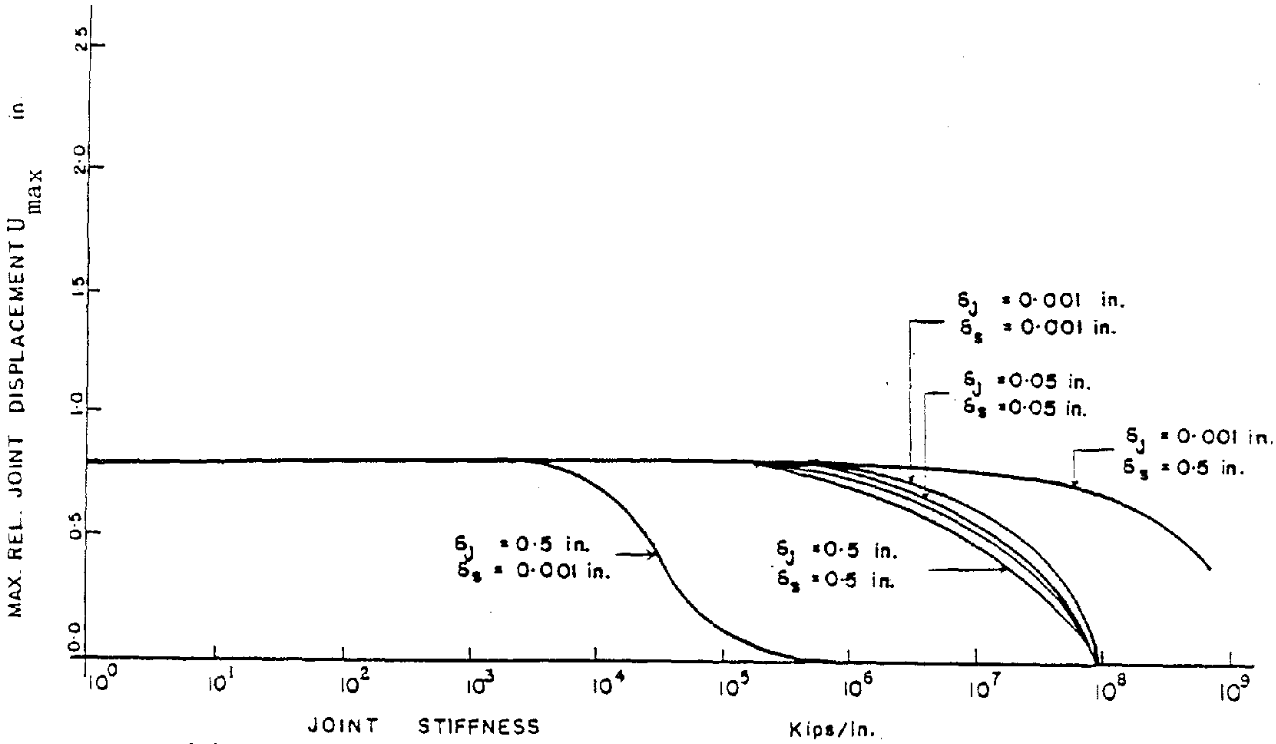
(b) Effect of Joint Stiffness on Relative Pipe Displacements (Joint Elastic, Soil Inelastic)

Figure II.10

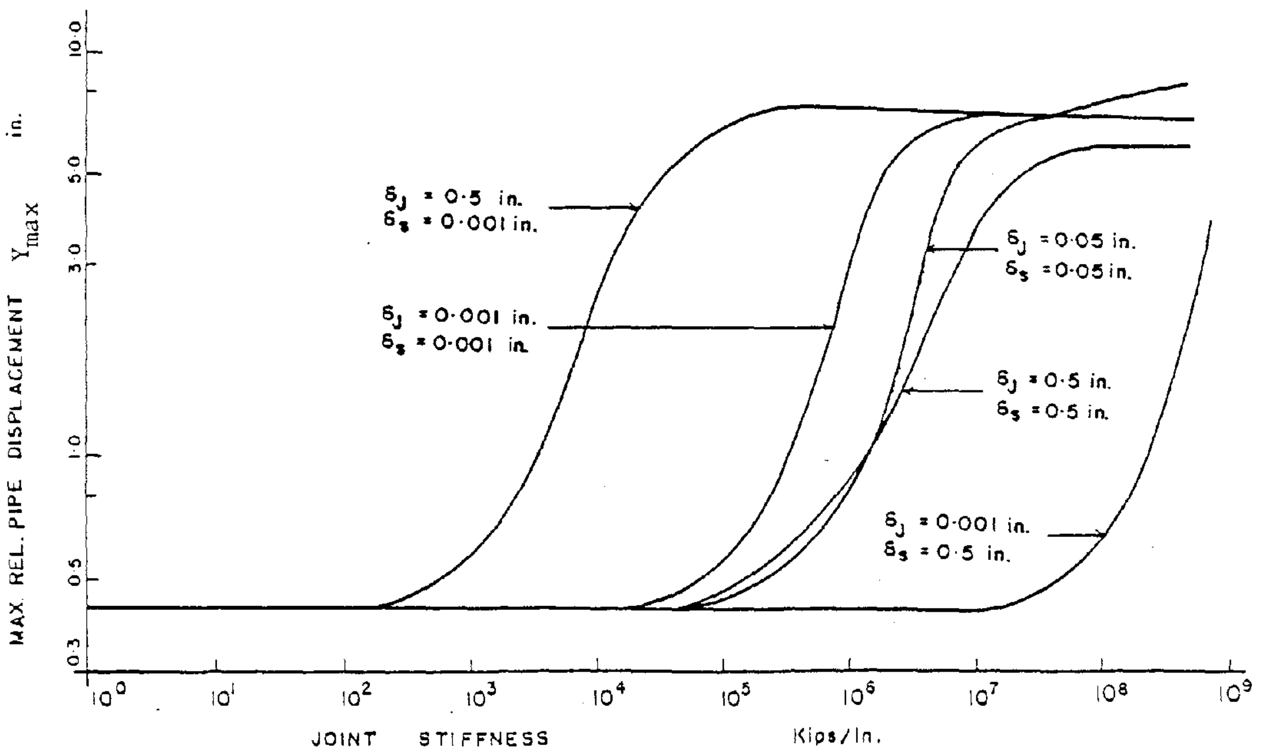


Effect of Joint Stiffness on Pipe Strains
(Joint Inelastic, Soil Inelastic)

Figure II.11

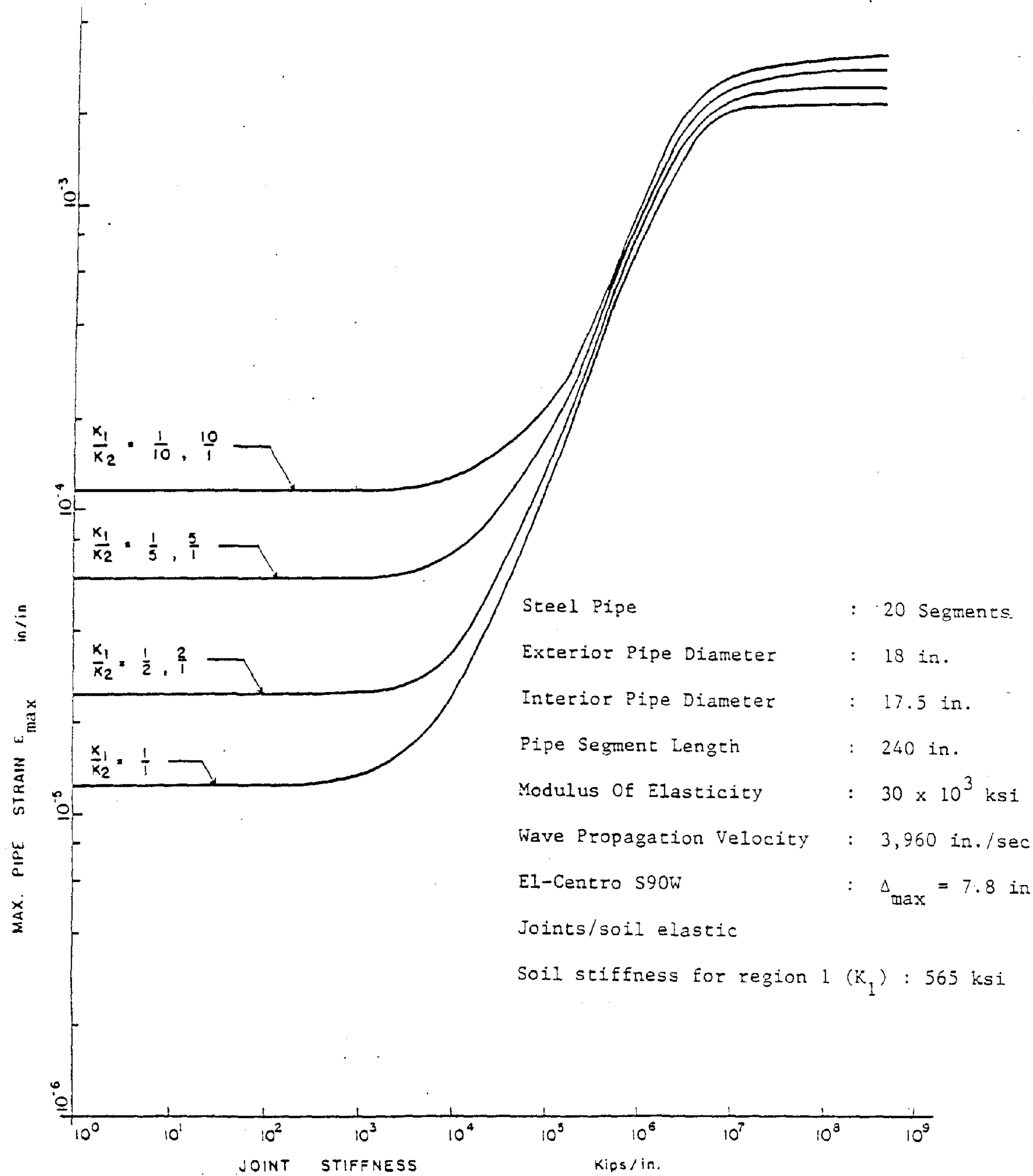


(a) Effect of Joint Stiffness on Relative Joint Displacements
(Joint Inelastic, Soil Inelastic)



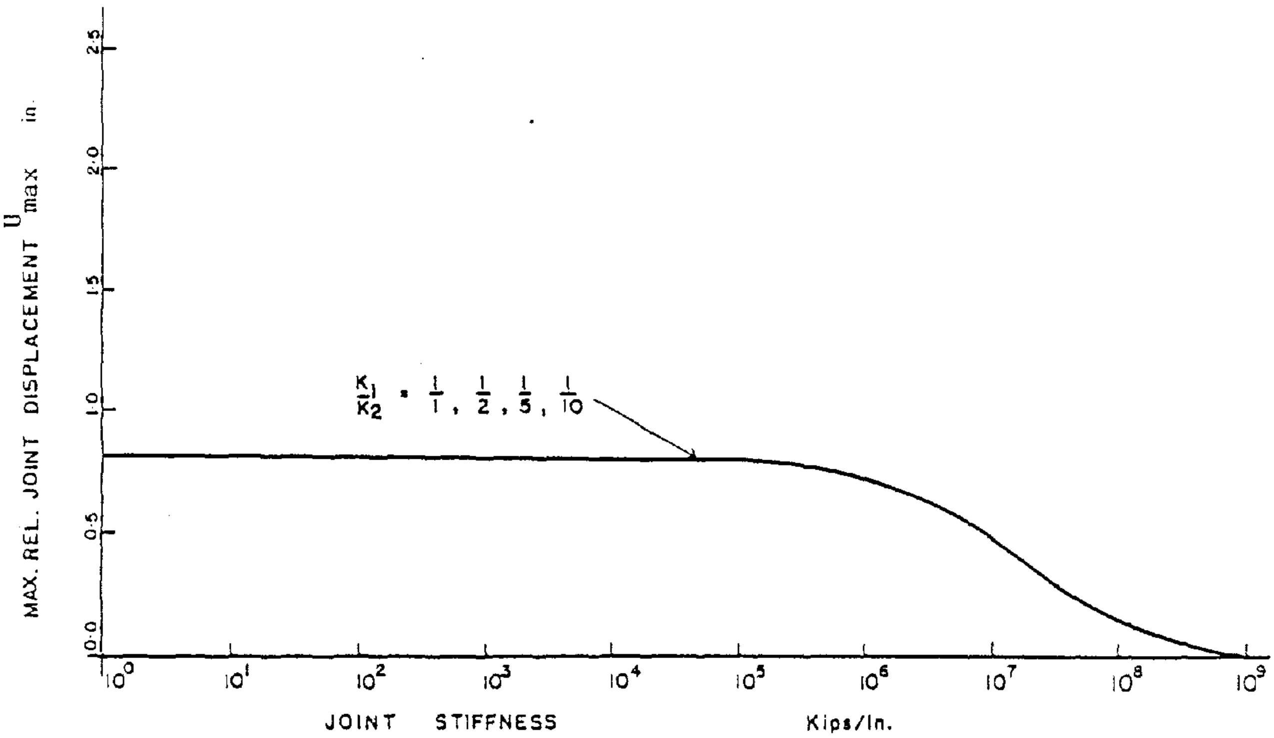
(b) Effect of Joint Stiffness on Relative Pipe Displacements
(Joint Inelastic, Soil Inelastic)

Figure II.12

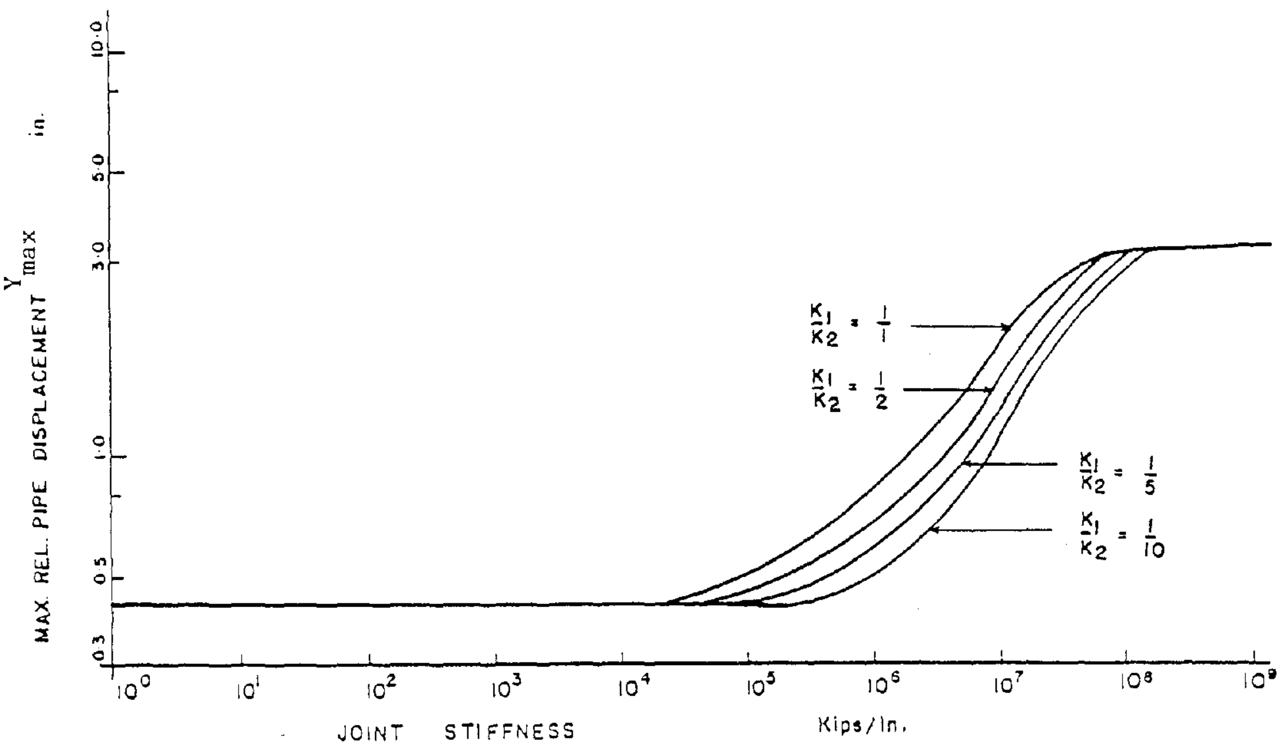


Effect of Soil Stiffness Changes on Pipe Strains (free-free ends)

Figure II.13

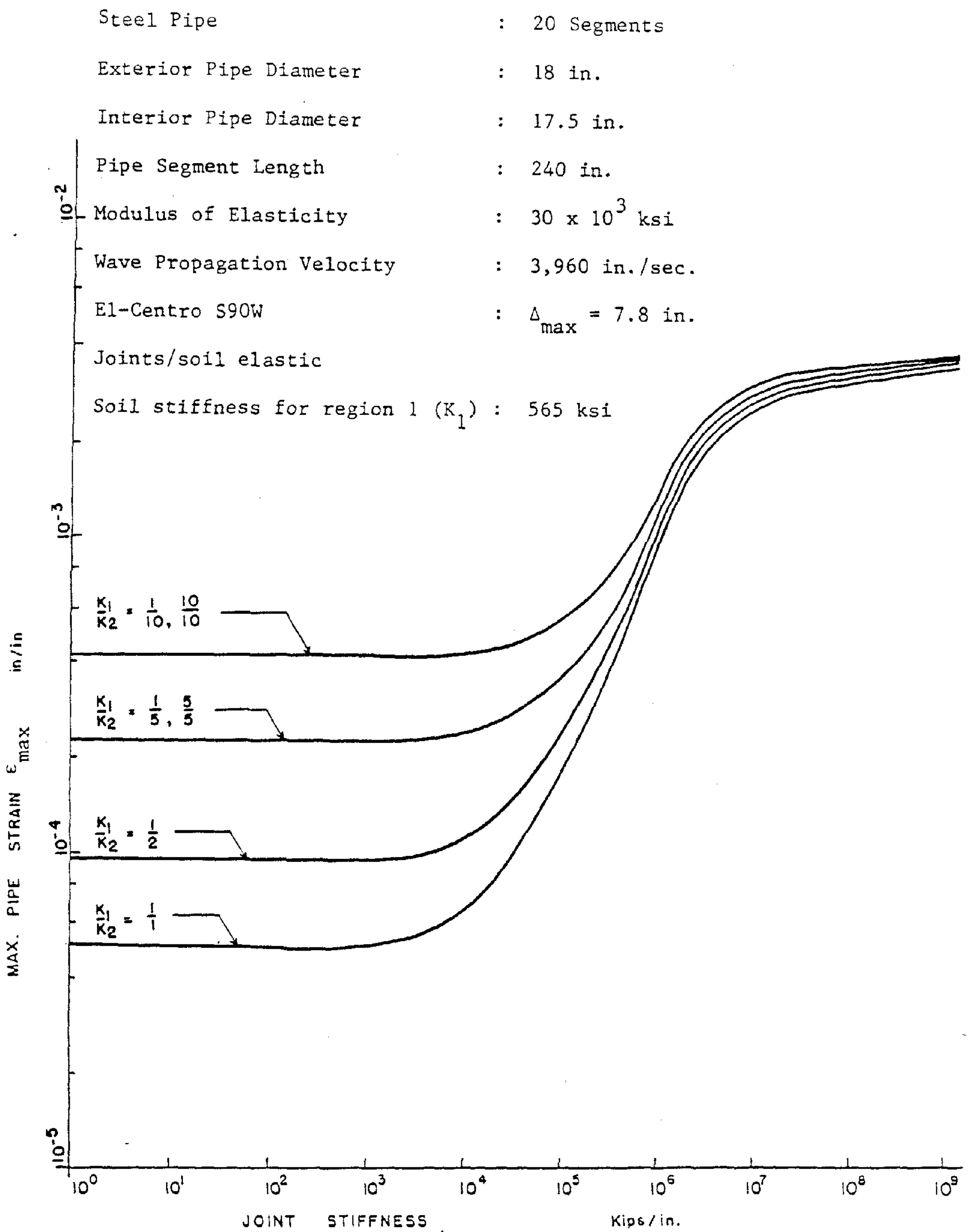


(a) Effect of Soil Stiffness Changes on Relative Joint Displacements (free-free ends)



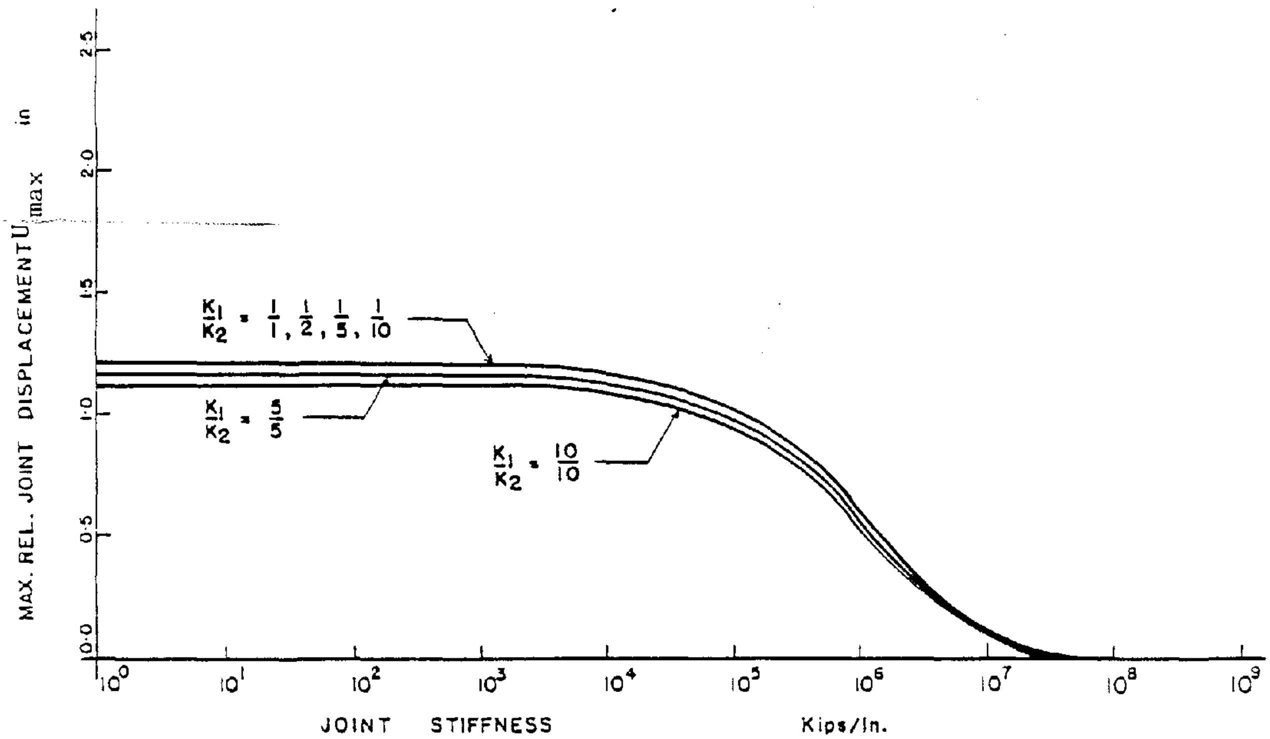
(b) Effect of Soil Stiffness Changes on Relative Pipe Displacements (free-free ends)

Figure II.14

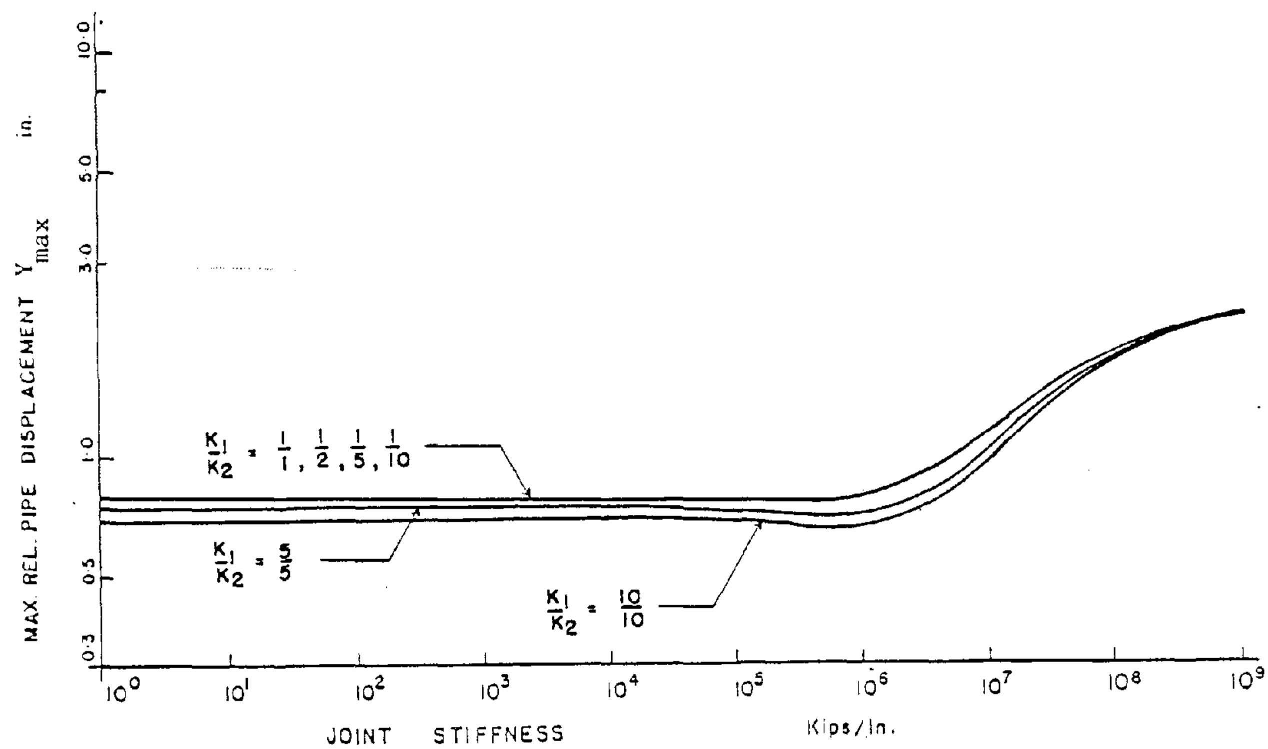


Effect of Soil Stiffness Changes on Pipe Strains
(fixed-fixed ends)

Figure II.15

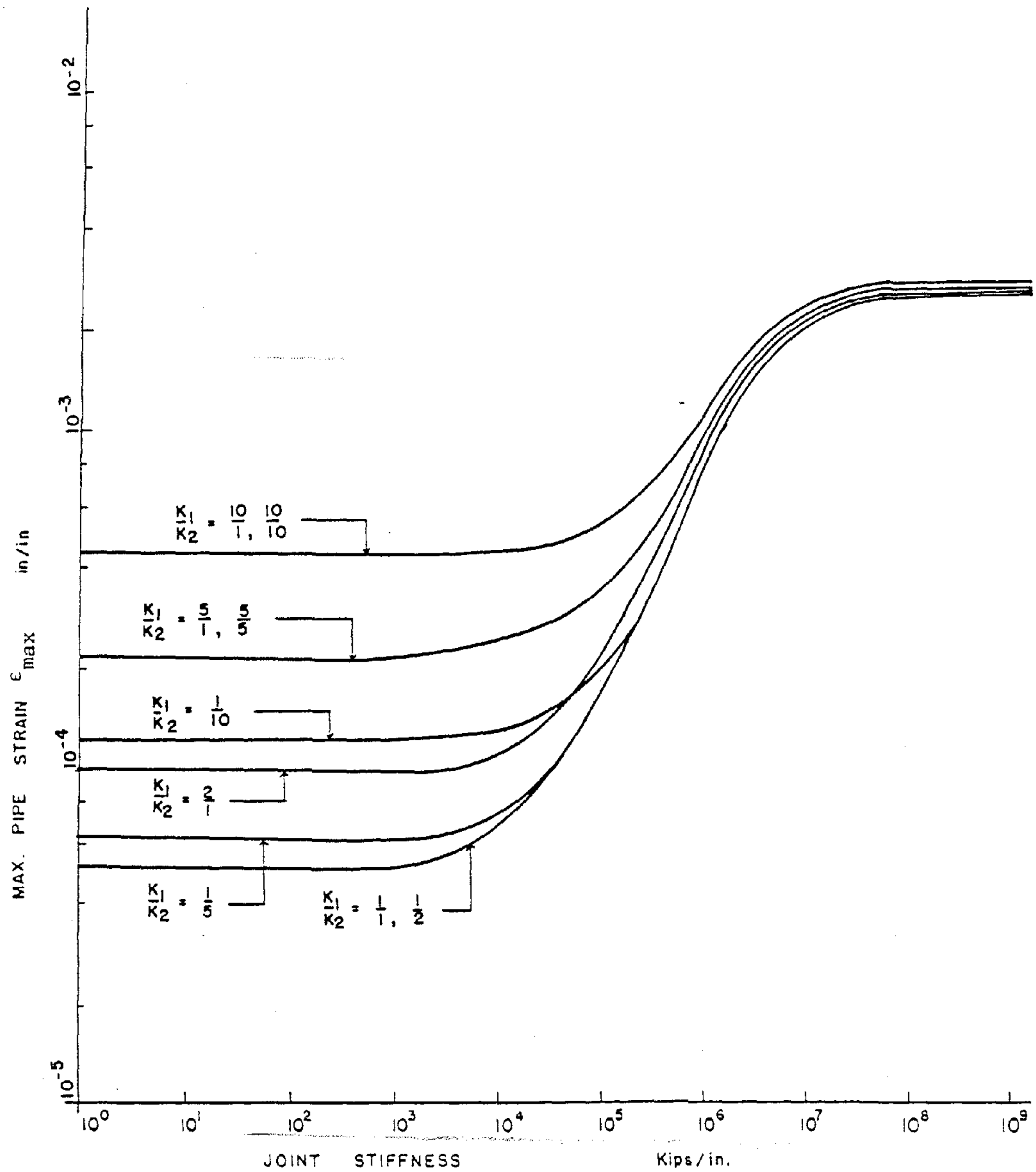


(a) Effect of Soil Stiffness Changes on Relative Joint Displacements (fixed-fixed ends)



(b) Effect of Soil Stiffness Changes on Relative Pipe Displacements (fixed-fixed ends)

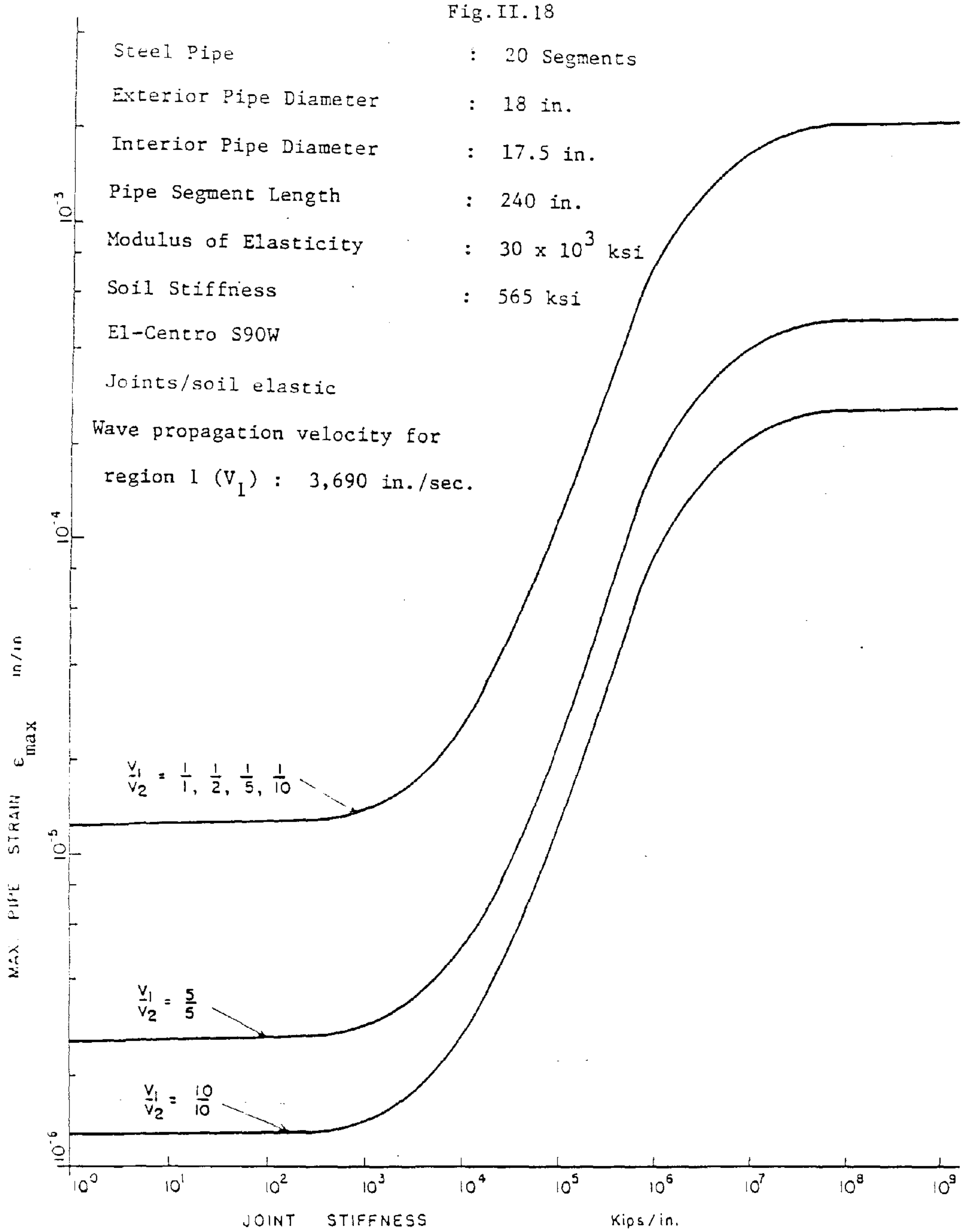
Figure II.16



Effect of Soil Stiffness Changes on Pipe Strains
(fixed-free ends)

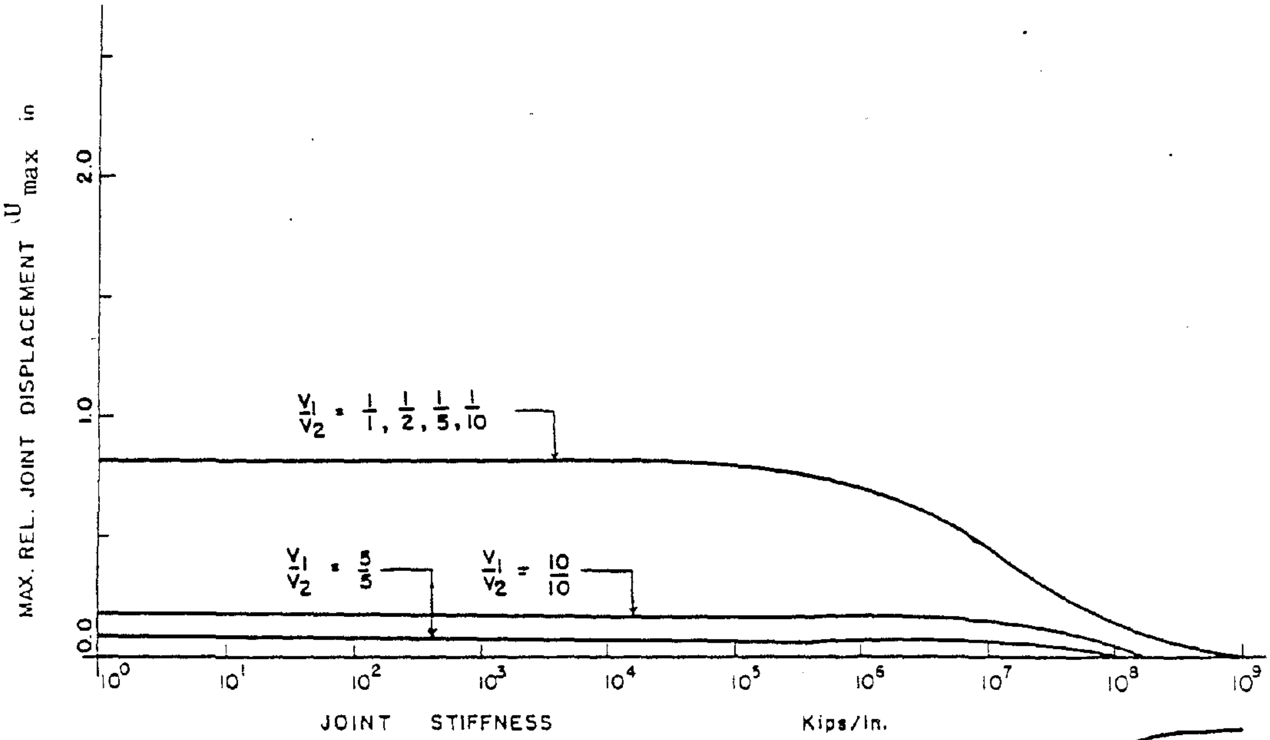
Figure II.17

Fig. II.18

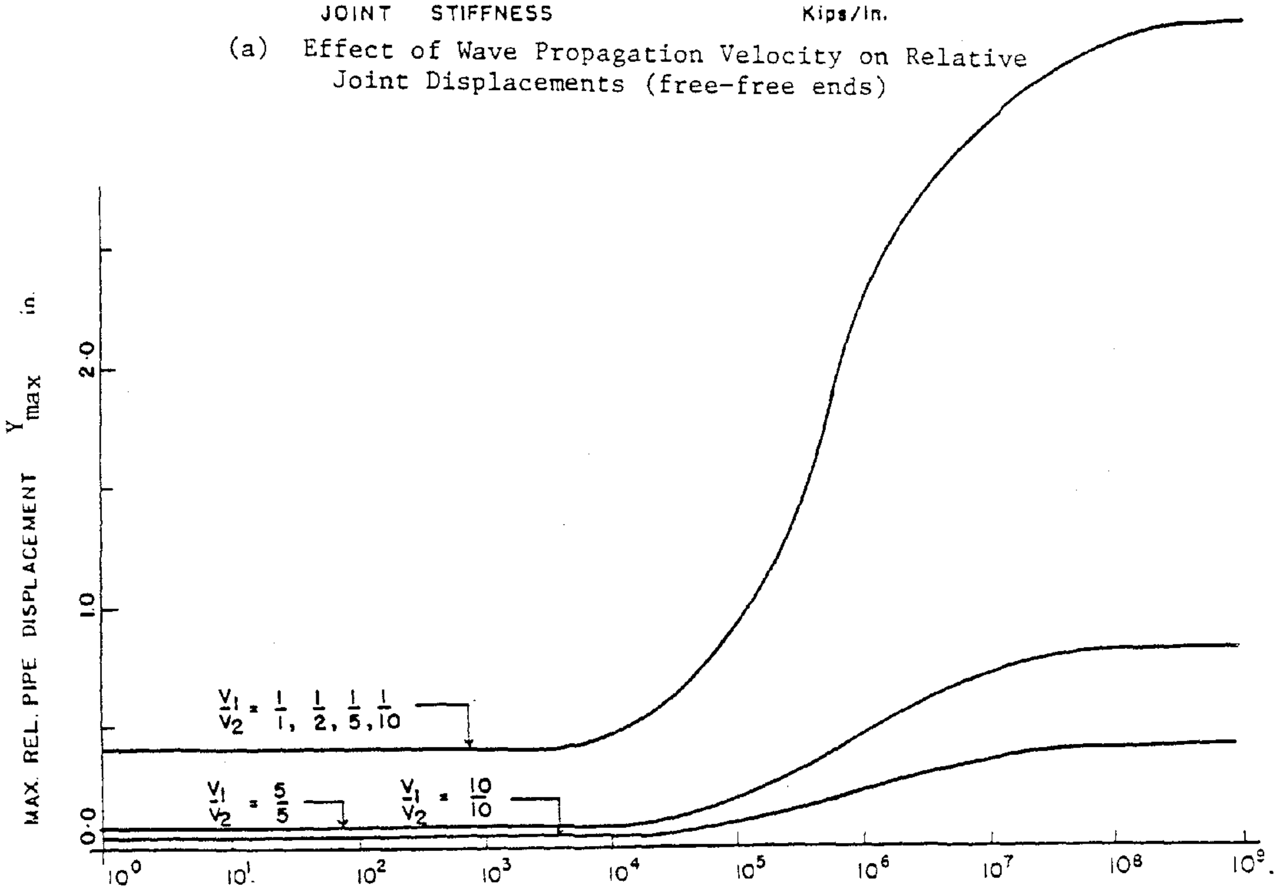


Effect of Wave Propagation Velocity Changes on Pipe Strains (free-free ends)

Figure II.18

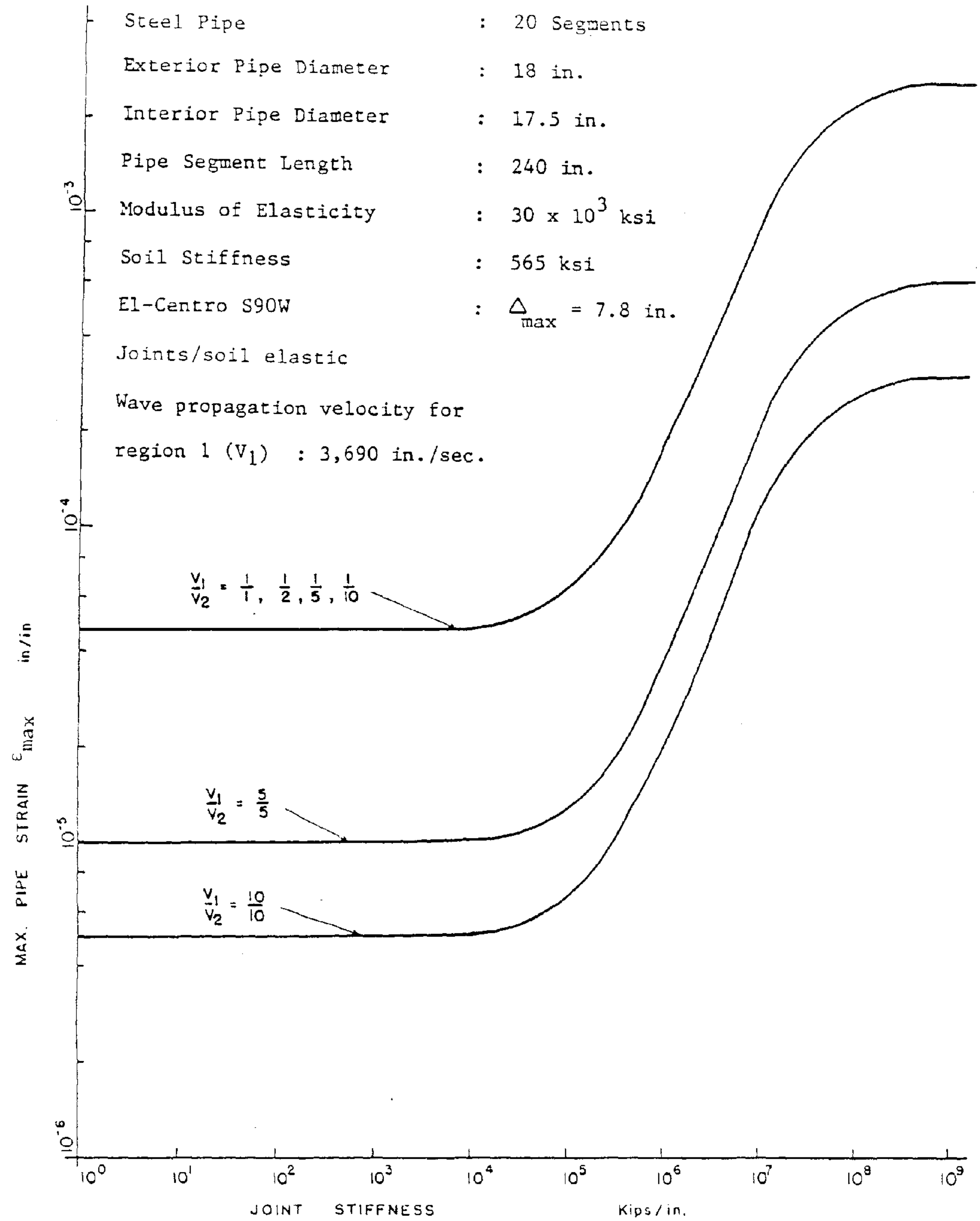


(a) Effect of Wave Propagation Velocity on Relative Joint Displacements (free-free ends)



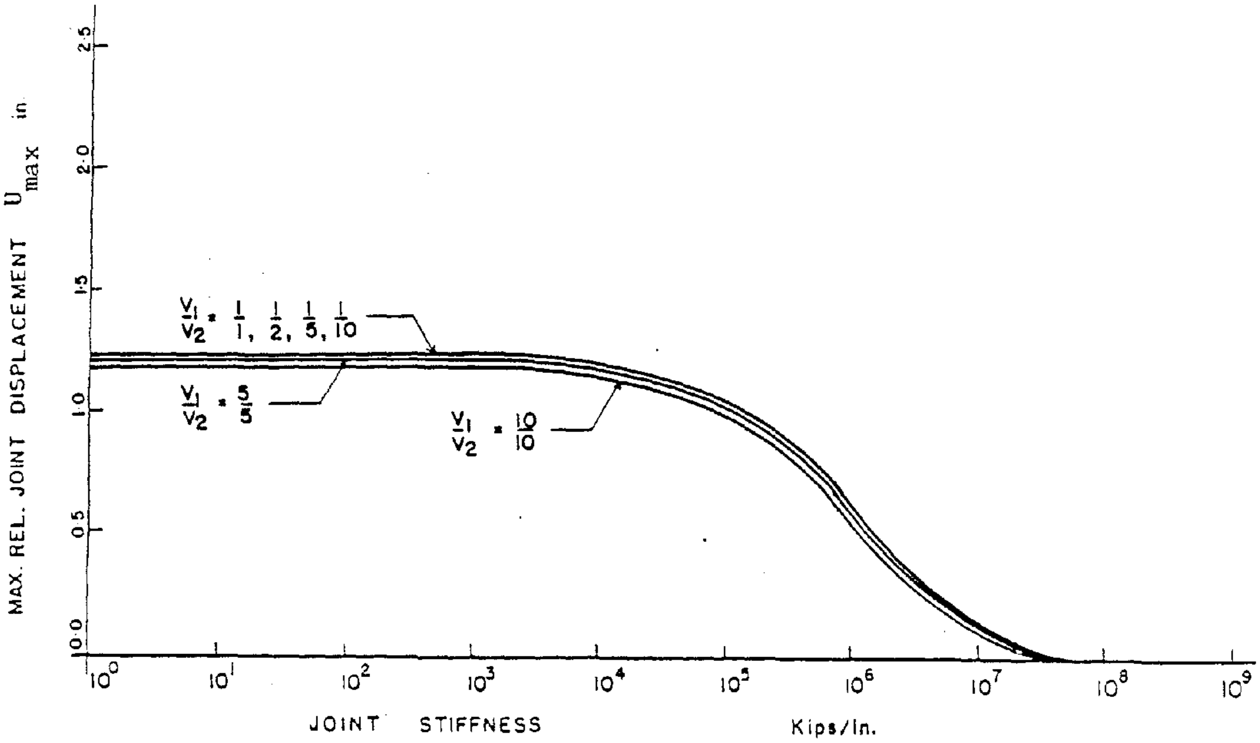
(b) Effect of Wave Propagation Velocity on Relative Pipe Displacements (free-free ends)

Figure II.19

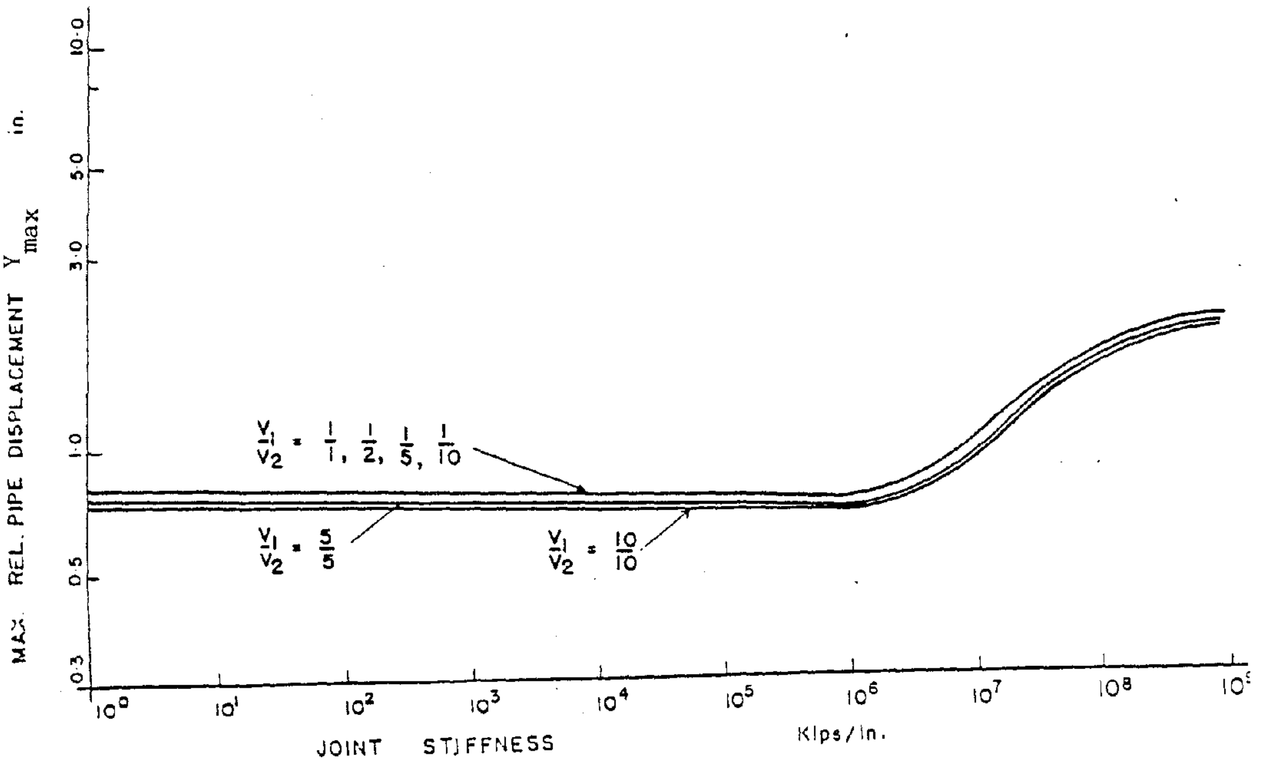


Effect of Wave Propagation Velocity on Pipe Strains
(fixed-fixed ends)

Figure II.20

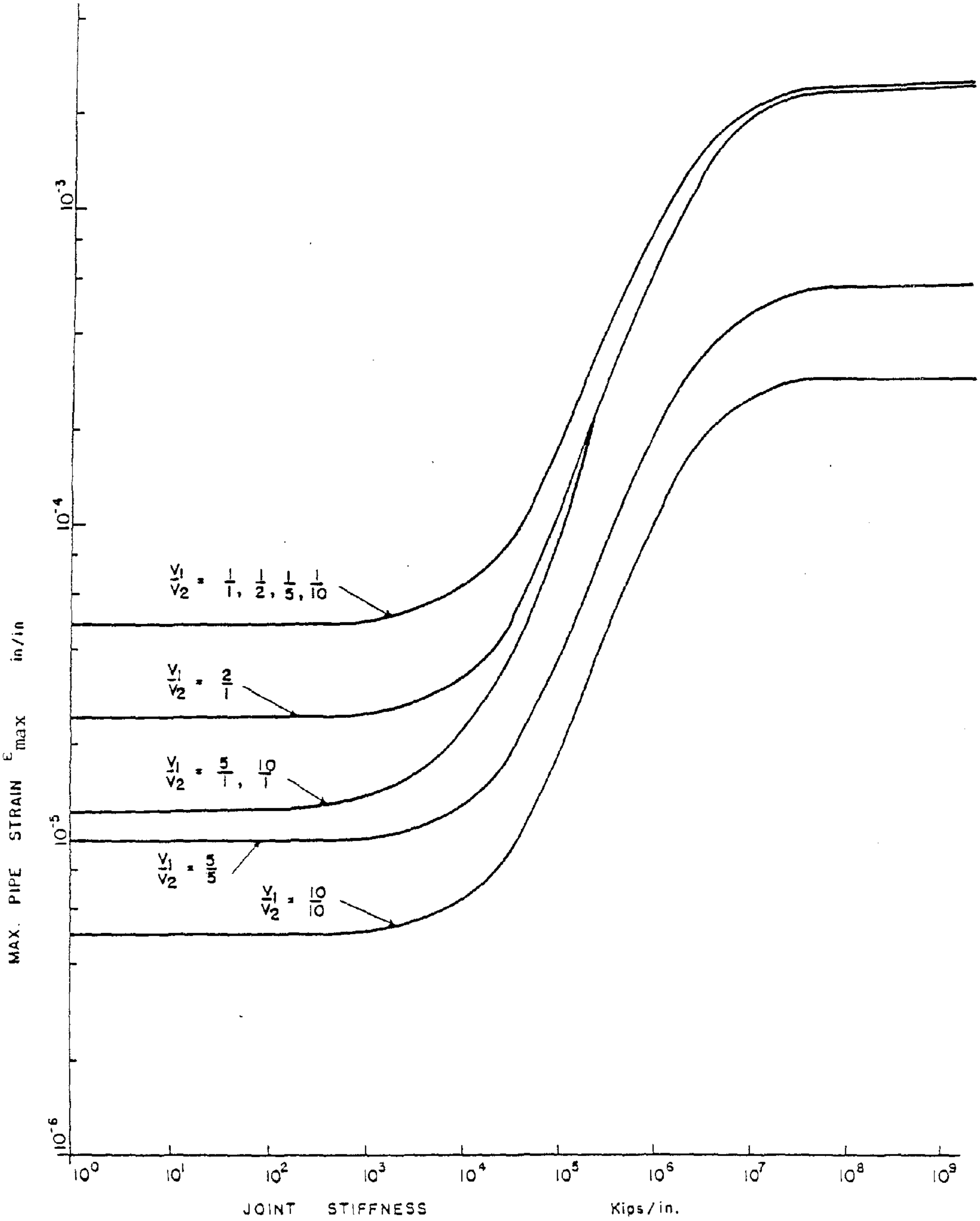


(a) Effect of Wave Propagation Velocity on Relative Joint Displacements (fixed-fixed ends)



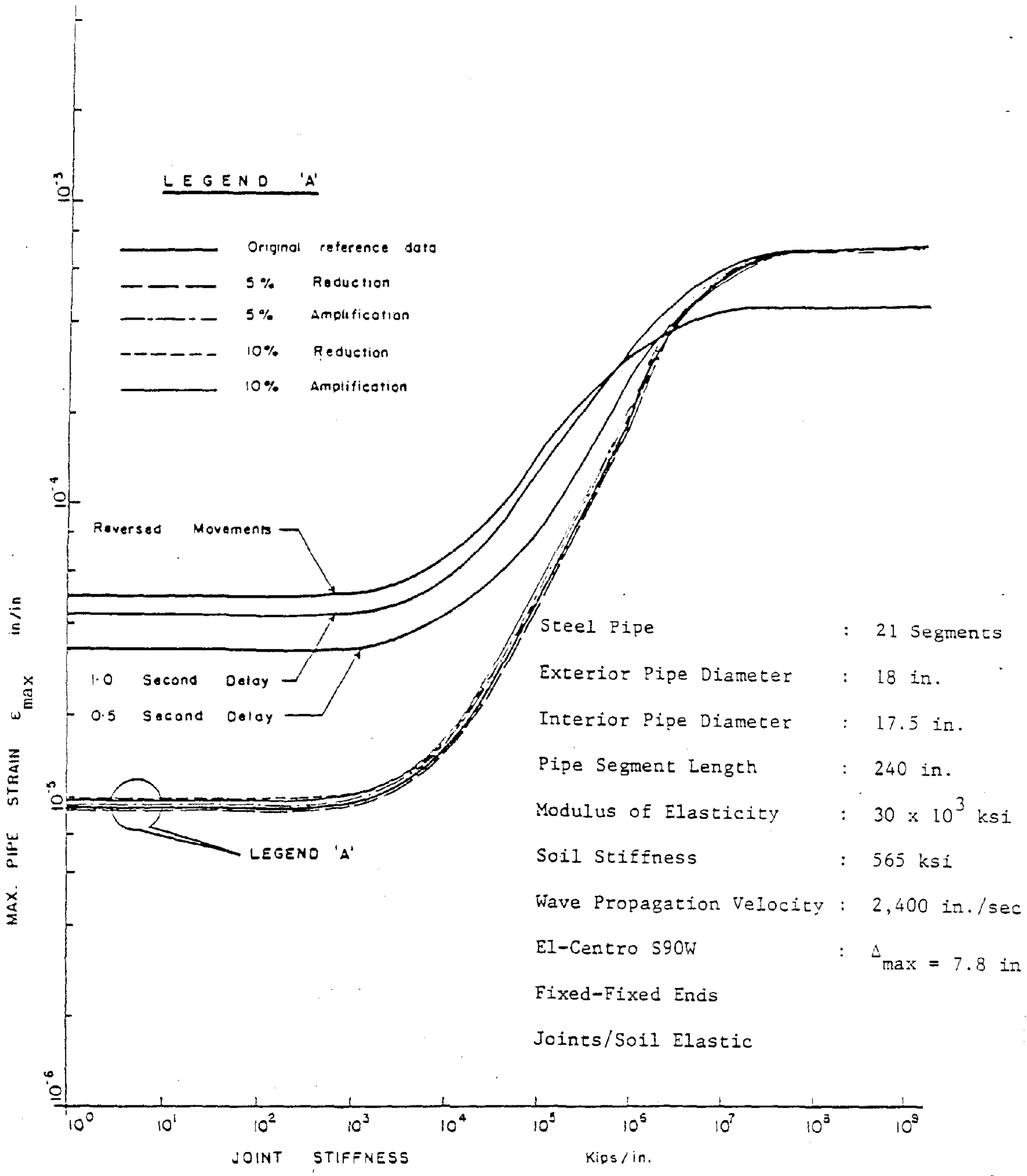
(b) Effect of Wave Propagation Velocity on Relative Pipe Displacements (fixed-fixed ends)

Figure II.21



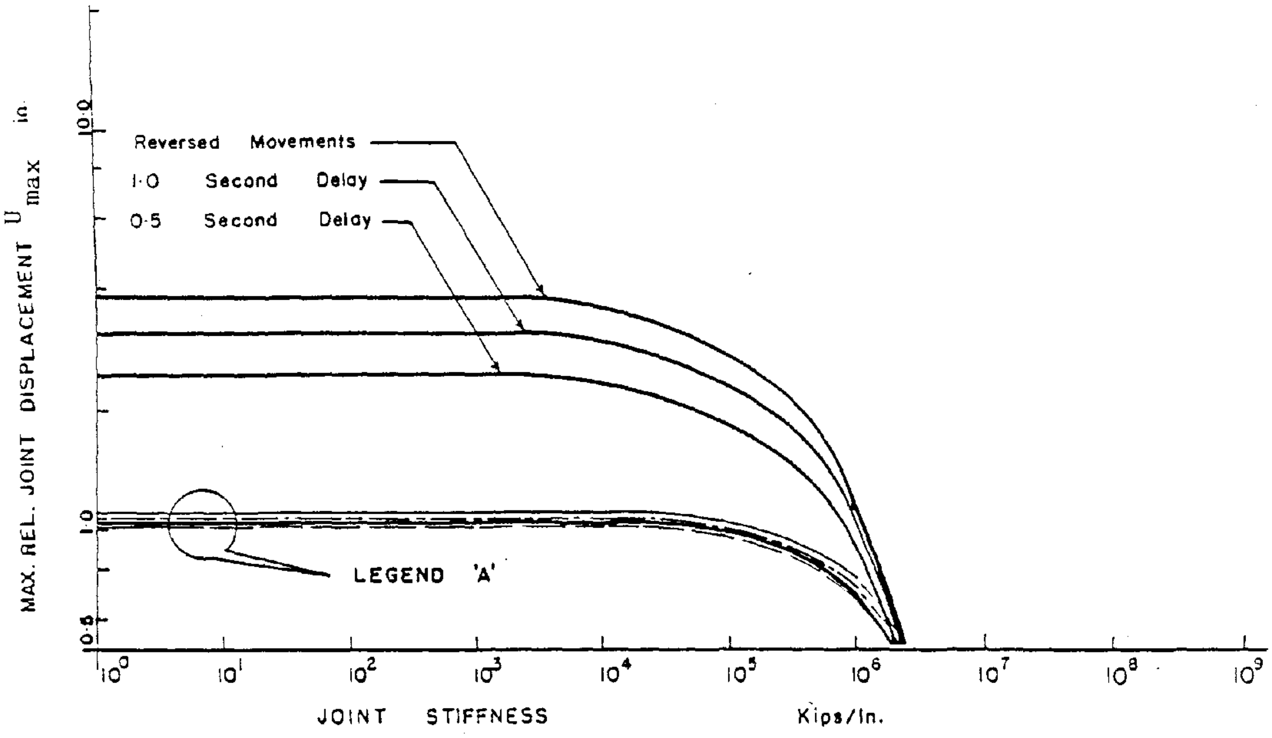
Effect of Wave Propagation Velocity on Pipe Strains
(fixed-free ends)

Figure II.22

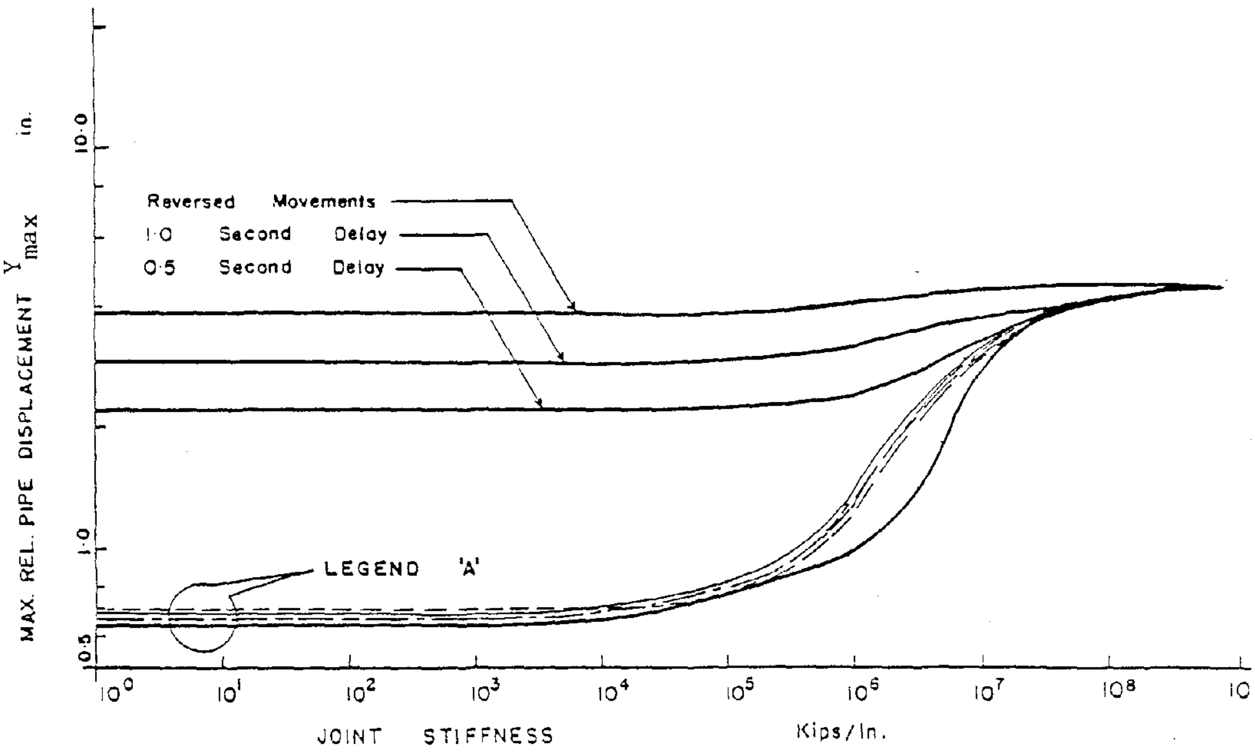


Effect of Siesmological Changes on Pipe Strains
(fixed-fixed ends)

Figure II.23



(a) Effect of Siesmological Changes on Relative Joint Displacements (fixed-fixed ends)



(b) Effect of Siesmological Changes on Relative Pipe Displacements (fixed-fixed ends)

Figure II.24

PART III

USER'S MANUAL

FOR THE COMPUTER PROGRAM ON

SEISMIC RESPONSE OF BURIED PIPELINES

III.1 Introduction

In earlier investigations (3,4,5), a quasi-static analysis model was developed to study the parametric response of buried pipelines, segmented or continuous, subjected to earthquake motion in the axial direction. However, only elastic resistance parameters for soil,joints are considered. No parametric elasto-plastic study has been done. In reality, both soil and joint does not remain elastic indefinitely. Therefore the quasi-static elasto-plastic analysis was undertaking to include the elastic-plastic behavior of the joint and soil to better understanding of siesmic responses of buried pipelines.

Based on the formulations from the "Quasi-Static Analysis Formulation for Buried Piping System" by Wang (4,5), a computer program was developed to analyze and obtain the responses of segmented, straight, buried pipelines due to seismic excitation. The basic output of the program are, the maximum pipe strain, maximum relative displacements between the pipe and the soil, and maximum joint displacements in the entire history of the ground excitation.

This report has modified the input/output format used in the earlier program to allow for more flexibility in the use of the program. The author has also modified the program such that it can be used to output the responses at any particular time(s) and many more.

This user's manual is intended to briefly inform the user of the capabilities of the computer program and to provide all the needed information to effectively use the program. The latest version of the computer program is now available for use as a package in the University of Oklahoma Computer System. The program is written in the Fortran Language and is named "QUAKE". The program listing is also included here for users outside of the University of Oklahoma Computer System. Various options for running the program, a complete description of the input file, and an example run are all presented in this part of the report.

III.2 Description of the Computer Program

II.2.1 General

The main objective of the computer program is to solve the equilibrium equation derived from the "Quasi-Static Analysis Formulation for Buried Piping System" by Wang (4,5), for the pipe segments nodal displacements $\{X\}$ as shown in Equation [1]. The program constructs a soil stiffness matrix $[\overline{K}_{soil}]$ from the soil properties input and multiplies it by a vector of ground displacements which is automatically obtained from the ground movement (earthquake) input . The program also constructs the pipeline system's stiffness matrix from the joints and pipe-segments properties input, which in turn is multiplied by an unknown vector of pipe displacements. This unknown vector of pipe displacements is the desired solution, which can be solved for by Gaussian elimination.

However, a non-linear behavior of the pipeline is expected, therefore, the program uses an interative process to provide the solution.

The program allows one to use various variable parameters as discussed in Section I.3 of this report, among which is the joint spring constants. With this variable, a free or fixed end piping system, as well as a continuous piping system, can be analyzed by specifying very stiff joint spring constants. Each pipe/joint properties are input separately, thus, allowing for variable pipe/joint characteristics along the pipeline system.

III.2.2 The Interative Process

The process starts by applying a very low fraction of the loading to ensure that all the elements of the pipeline, pipes and soil-pipe interfaces, behave elastically. After this the system is scanned to find the highest stressed element in comparison to its elastic limit. Once the element is found, the same loading is increased to a fraction over the one that produces the first plastic condition.

At this point, the necessary corrections are made to the elastic stiffness matrices to include the plastic behavior encountered and the loading is increased further always checking to see if other elements have become plastic. This last process is repeated over and over again until full loading condition is obtained, depending on the number of iterations desired.

Two iterations are done at full load, one is to obtain the total loading from a lower step and the other is to ensure convergence.

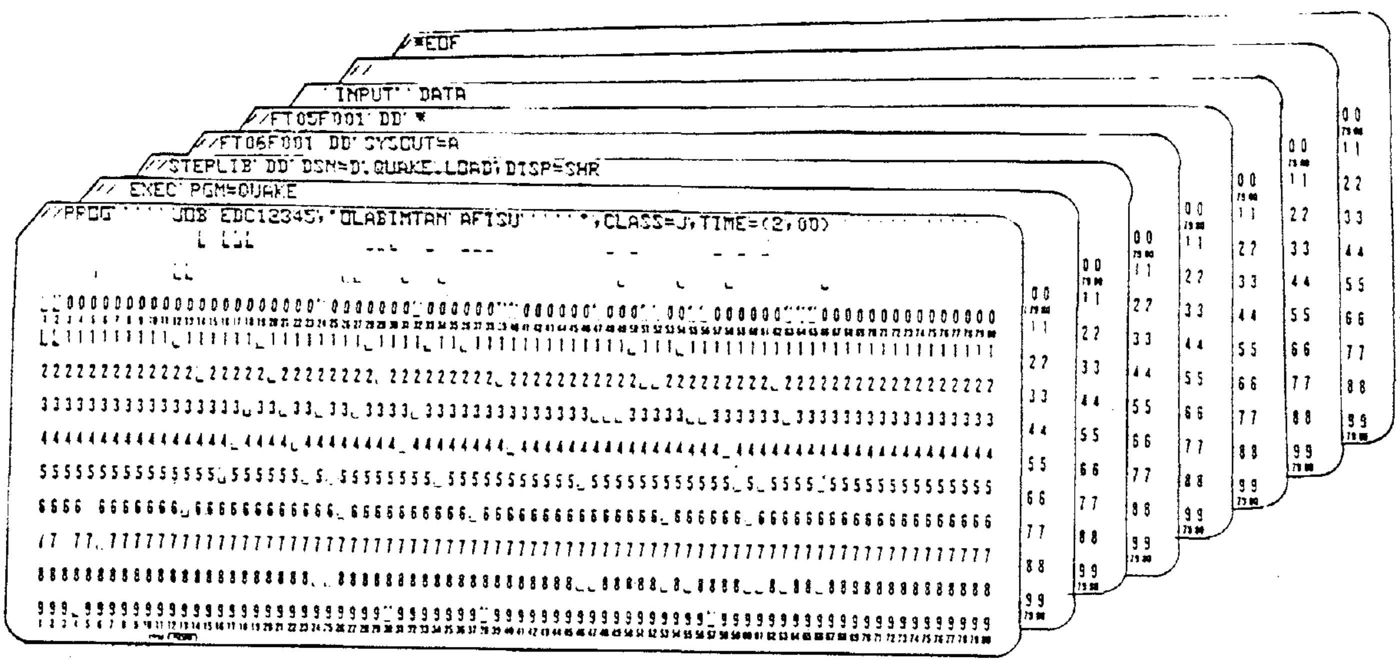
On the other hand, if the system is scanned and no element is found to become plastic, full load is applied and the resulting displacements are saved after solving the system.

III.2.3 Time Steps

The same procedure described before is repeated for the next loading in the earthquake history. In the case of the El Centro Earthquake of 1940, it involved 536 different loading conditions, if the entire earthquake record is to be used. (see Table II.1)

III.3 Example Job Control Statements

1. To execute the program package on the University of Oklahoma Computer System through a card deck.

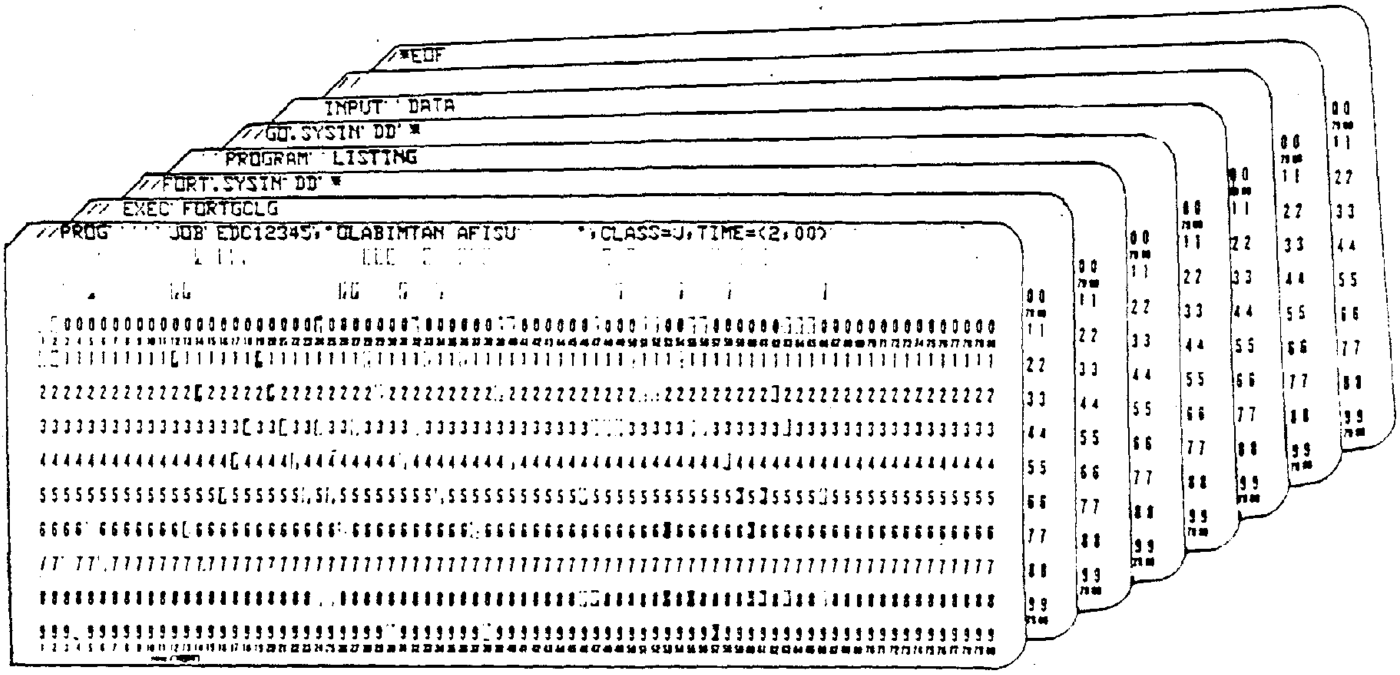


2. To execute the program package on the University of Oklahoma Computer System through a terminal.

```
//PROG JOB EDA12345,'AFISU OLABIMTAN',CLASS=J,TIME=(3,00)
// EXEC PGM=QUAKE
//STEPLIB DD DSN=D.QUAKE.LOAD,DISP=SHR
//FT06F001 DD SYSOUT=A
//FT05F001 DD *
   INPUT DATA
/*EOF

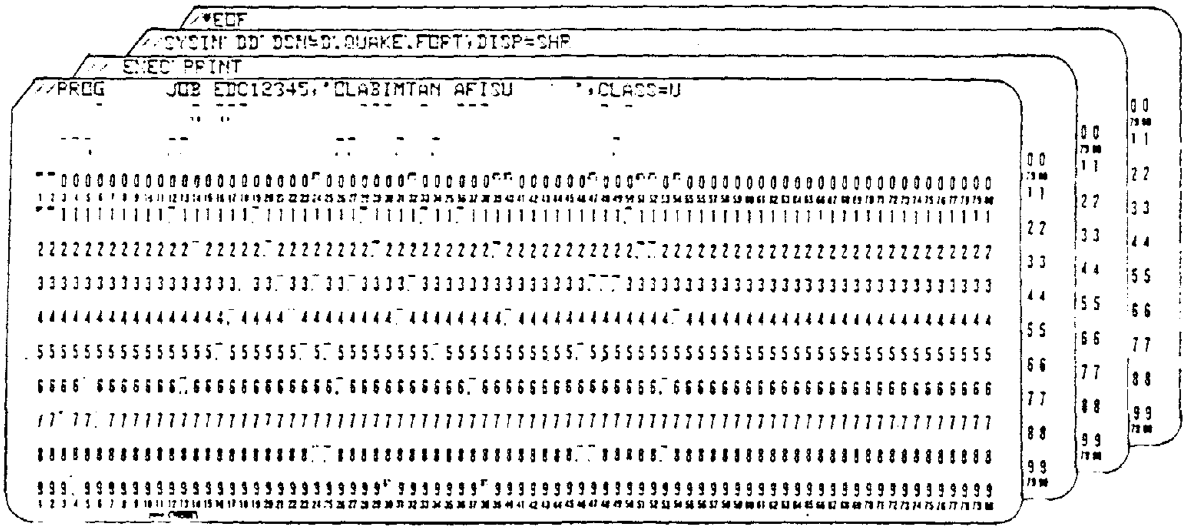
SEND 'PROG'
```

3 To execute the computer program with the program listing.



4. To obtain the program listing directly from the University of Oklahoma Computer System.

through a card deck :



.through a terminal :

```
//PROG JOB EDA12345,'AFISU OLABIMTAN',CLASS=U
// EXEC PRINT
//SYSIN DD DSN=D.QUAKE.FORT,DISP=SHR
/*EOF

SEND 'PROG'
```

III.4 Description of the Input File

III.4.1 Set 1 (Earthquake Record Information)

A. CONTENTS (One Card Required)

B. READ IPT, IGM

where:

IPT = The number of regions where different earthquake data are input to the system. (Maximum IPT is 4.)

IGM = The number of earthquake data recorded at each region. This number must be the same for all the regions. (Maximum IGM is 600.)

C. FORMAT (2I5)

D. EXAMPLE IPT = 3, IGM = 174, means that, the piping system is subjected to 3 different earthquake motions in 3 regions, and 174 earthquake data are recorded at each region.

III.4.2 Set 2 (Earthquake region information required only if IPT is greater than 1)

A. CONTENTS (Number of Cards = IPT)

B.
```
   DO 31 I = 1, IPT
   READ JOINT (I, J), J = 1, 2
31 CONTINUE
```

where:

JOINT (I, J) = The matrix that stores the joint numbers, described below.

Card 1

JOINT (1, 1) = The near(starting) joint number for earthquake record at region 1.

JOINT (1, 2) = The far (ending) joint number for earthquake record at region 1.

Card 2

JOINT (2, 1) = The near (starting) joint number for earthquake record at region 2.

JOINT (2, 2) = The far (ending) joint number for earthquake record at region 2.

Card I

JOINT (I, 1) = The near (starting) joint number for earthquake record at region I.

JOINT (I, 2) = The far (ending) joint number for earthquake record at region I.

C. FORMAT (2I5)

D. EXAMPLE If earthquake is constant over the entire pipeline, (IPT = 1), Card Set 2 is not required. Here, all the ground movement records are input from one region. The default is JOINT (1, 1) = 1 and JOINT (1, 2) = NJ where NJ is the number of joints. If earthquake is input for 3 regions for example, (IPT = 3), 3 Cards (Set 2) are required.

If there are 21 joints in the pipeline (numbered 1 to 21), if one wants Joint 1 to 5 to use the records for region 1, then Card 1 must contain integers 1 and 5. If one wants Joints 6 to 14 to use the records for region 2, then Card 2 must contain the integers 6 and 14. Lastly, Card 3 must contain the integers 15 and 21, since Joints 15 to 21 uses the record for region 3 in this case.

E. NOTES

1. If one decides not to use the record from a particular region I, which is part of the earthquake data set, the corresponding Joint Card must be left blank. From the example above, if one decides not to use the earthquake data for region 2 in a particular run, and wants Joints 1 to 10 to use records for region 1 and Joints 11 to 21 to use the records for region 3. This can be done in 2 ways:

   I. Remove the data set for location 2 and change IPT to 2, then,

      Card 1 contains 1, 10

      Card 2 contains 11, 21

   II. Keep all data set and IPT remains as 3, then,

      Card 1 contains 1, 10

      Card 2 contains 0, 0

      Card 3 contains 11, 21

III.4.3 Set 3 (Earthquake Record)

A. CONTENTS (Number of Cards = IPT * IGM1)

B.

```
    DO  6   JJ = 1, IPT
    DO  1    I = 1, IGM1
    J = I * 8
    K = J - 7
    READ   GMOVE (II,JJ), II = K,J
  1 CONTINUE
  6 CONTINUE
```

where:

GMOVE (II,JJ) = The matrix of ground movement records.

IGM1 = The number cards/lines containing the earthquake record for region JJ (For JJ = 1 to IPT). This number is computed automatically from IGM.

Cards — There must be 8 records per card/line except for the last card/line which may contain less than 8 records. Otherwise blanks will be considered as zeros.

C. FORMAT (8F10.4)

D. EXAMPLE — If there are three regions of record and

250 datas recorded at each region. The 250 data from region 1 is read in first, then 250 data from region 2 is read in next, and lastly the data from region 3. The order must correspond to the order of joint numbering in Set 2 above. For each region I, 250 data is required to be read in. Since 250/8 = 31.25 is not an integer, IGM1 is taken as 32 in the program, and the data cards must be as follows.

Card 1 Contains GMOVE (I,J), J = 1 to 8

Card 2 Contains GMOVE (I,J), J = 9 to 16

.

.

.

Card 31 Contains GMOVE (I,J), J = 241 to 248

Card 32 Contains GMOVE (I,J), J = 249 to 250

Here Card #32 contains 2 records in its first 20 columns only.

E. NOTES:

1. For this example a total of 3 x 32 = 96 cards/lines are required.
2. Begin earthquake records for each region on a new card/line.
3. Time interval between records must be 0.1 seconds.

III.4.4 <u>Set 4</u> (For Output Choice)

A. CONTENTS (One Card Required)

Basically, this program obtains and outputs the maximum responses for the entire period of ground excitation, such as the maximum pipe strains, maximum joint displacements, etc. This program outputs the maximum pipe strain and the corresponding time of occurence for each pipe segment. Sometimes one is interested in knowing what are the responses, including the ground displacement itself, at a particular time (or times). For example, what are the free field ground displacement and response at various nodes at times = 2.5 sec., 3.7 sec., etc.

Also part of the basic output is the absolute maximum response in all of the pipes/joints, the corresponding pipe/joint number and the time of occurence. Again, one may be interested in knowing what are the responses in all the pipes/joints, including free field displacement wave shape at the times when the absolute maximum response is experienced. The next input data (KLIST, ILIST) enables one to do these two things.

B. READ ILIST, KLIST

where: ILIST > 0 ILIST, any integer greater than zero. To output (freeze) the responses and the corresponding free field displacement at the times when the absolute maximum response in all the pipes/joints occur.

ILIST = 0	ILIST equals to zero, if one does not want to output the responses at the times when the absolute maximum response occur.
KLIST > 0	KLIST, an integer greater than zero, is the number of times that one wants to output (freeze) the induced ground displacements and responses. For example, if one wants to output the general responses at times = 3.6 sec., 12.9 sec., respectively, KLIST = 2 (maximum KLIST is 5).
KLIST = 0	KLIST equals zero, when one does not want to output the responses at any particular time.

C. FORMAT (2I5)

III.4.5 Set 5 (Time(s) for which the responses are to be output)

A. CONTENTS (One Card Required)

B. IF (KLIST. NE. 0) READ TIME(I), I = 1,5

where:

TIME(I)	The vector that stores the times for which the responses are to be output. (Maximum I = 5.)

C. FORMAT (5F10.4)

D. EXAMPLE — As in the above example, to output the responses at times 3.6 sec. and 12.9 sec., respectively (KLIST = 2). This card must contain 3.6 in its first 10 columns and 12.9 in its next 10 columns.

E. NOTE : — This card is required only when KLIST is greater than zero.

(Continued)

III.4.6 Set 6 (Parameter for non-linear analysis)

A. CONTENTS (One Card Required)

B. READ PERI, XITER

where:

PERI = Initial percentage of total load, preferably 0.1.

XITER = Number of iterations per loading.

C. FORMAT (2F10.5)

III.4.7 Set 7 (Study time interval)

A. CONTENTS (One Card Required)

B. READ STTM(I) I = 1, 20

where:

STTM(I) The vector that stores the pairs of time periods at which one wants to know the displacements or strains in the system.

C. FORMAT (20F4.1)

D. EXAMPLE If one wants to know the strains and displacements in the system for the intervals of time 3.5 to 3.7 seconds and 11.8 to 12.4 seconds; STTM(1) = 3.5, STTM(2) = 3.7, STTM(3) = 11.8, STTM(4) = 12.4.

These times must increase contonically; that is, the first intervals wanted must come first in time.

E. NOTE — If one wants only the maximum values in the entire load history, this card must be left blank.

III.4.8 Set 8 (Basic Parameters)

A. CONTENTS (One Card Required)

B. READ NS, TS, TE, TI

where:

NS = Number of pipe segments.

TS = Starting time in the earthquake record for calculations.

TE = End time for calculations.

TI = Time interval desired. (Must be a multiple of 0.1)

C. FORMAT (I5, 3F10.4)

D. EXAMPLE — In the case of El-Centro earthquake, the total time of record is 53.6 seconds. In order to obtain the responses for the entire time of record, TS = 0.0 and TE = 53.6. But the responses can be obtained for a time interval 2.3 to 9.6 seconds only, then, TS = 2.3 and TE = 9.6

III.4.9 Set 9 (Title)

A. CONTENTS (at least 1 card required)

B. READ K, NTITLE(I), I = 23, 60

where:

K = 1	K, an integer equals one, indicates one more card is to be read.
K ≠ 1	K is not equal to one (i.e., zero), indicates the last card to be read in.
NTITLE(I)	A character vector that stores and outputs the title on a card/line. Each title on a card must fit within columns 2 and 80.

C. FORMAT (I1, 79A1)

D. EXAMPLE — If one wants to input 4 lines of title, 4 cards of Title are required, with K = 1 on the first three cards and K = 0 on the last card.

E. NOTE : There must be at least one card and no maximum number of cards.

III.4.10 Set 10 (Joint Properties)

A. CONTENTS (NJ Cards)

```
        DO  11  I = 1, NJ
B.      READ  KJOI(I), DJOI(I)
     11 CONTINUE
```

where:

NJ = The number of joints (NJ = NS + 1).

KJOI(I) = Stiffness of joint I.

DJOI(I) = Maximum elastic displacement for joint I.

C. FORMAT (2E15.9)

D. NOTE There must be NS + 1 cards.

III.4.11 Set 11 (Pipe Segment Properties)

A. CONTENTS (NS Cards)

```
B.      DO  12  I = 1, NS
        READ DI, DE, LEN(I), ELAS(I), SST(I) VELS(I), DSOI(I)
     12 CONTINUE
```

where:

DI = Internal diameter of pipe segment I.

DE = External diameter of pipe segment I.

LEN(I) = Length of pipe segment I.

ELAS(I) = Modulus of elasticity of pipe segment I.

SST(I) = Soil stiffness along pipe segment I.

VELS(I) = Wave propagation velocity along pipe segment I.

DSOI(I) = Maximum elastic relative displacement between pipe and soil, along pipe segment I.

C. FORMAT (7E11.5)

D. NOTE There must be NS cards.

<u>End of input data</u>.

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APPENDIX A

PROGRAM LISTING

```
C***************************
C
      REAL*8 SYS,SOIL,X
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
      DIMENSION VELS(30),STTM(20)
C
      READ(5,150) IPT,IGM
      IF(IPT.EQ.1) GO TO 7
      DO 31 I=1,IPT
      READ(5,150) (JOINT(I,J), J=1,2)
   31 CONTINUE
    7 CONTINUE
      IGM1=IFIX(IGM/8.)
      IF((IGM-IGM1*8).GE.1) IGM1=IGM1+1
      DO 6 JJ=1,IPT
      DO 1 I=1,IGM1
      J=I*8
      K=J-7
      READ(5,2) (GMOVE(II,JJ),II=K,J)
    2 FORMAT(8F10.4)
    1 CONTINUE
    6 CONTINUE
      DO 74 I=1,4
      ZBC(I)=0.
      ZT(I)=0.
   74 CONTINUE
      READ(5,150) ILIST,KLIST
  150 FORMAT(2I5)
      IF(KLIST.NE.0) READ(5,151) (TIME(I), I=1,5)
  151 FORMAT(5F10.4)
      PI=3.141593
      ITM=1
      NTOT=0
      READ(5,3)PERI,XITER
      READ(5,40)(STTM(I),I=1,20)
   40 FORMAT(20F4.1)
      READ(5,4)NS,TS,TE,TI
    3 FORMAT(2F10.5)
    4 FORMAT(I5,3F10.4)
      NJ=NS+1
      NJ2=2*NJ
      NS2=2*NS
      NSYS=3*NS2-2
      NSOI=4*NS
      CALL START(NS,NJ,TS,TE,TI,PERI,XITER,NSYS)
      WRITE(6,8)
    8 FORMAT('1',26X,25('*'),/,27X,'*',23X,'*',/,27X,'*',3X,
     1'JOINT PROPERTIES',4X,'*',/,27X,'*',23X,'*'/27X,25('*')/'0'/
     215X,'JOINT',5X,'STIFFNESS',6X,'MAXIMUM ELASTIC DISPLACEMENT'/'0'/
      DO 11 I=1,NJ
      READ(5,9) KJOI(I),DJOI(I)
```

```
142 WRITE(6,10) I,KJCI(I),DJCI(I)
 11 CONTINUE
  9 FORMAT(2E15.9)
 10 FORMAT(13X,I5,7X,E10.4,12X,E10.4)
    WRITE(6,14)
 14 FORMAT('1',25X,28('*'),/,26X,'*',26X,'*',/,26X,'*',3X,
   1'PIPELINE  PROPERTIES',3X,'*',/,26X,'*',26X,'*',/
   2,26X,28('*'),/'0'/5X,'PIPE',2X,'I.DIAMETER',2X,'EX.DIAMETER',
   34X,'AREA',4X,'M.ELASTICITY',3X,'LENGTH'/'0'/)
    ATD(1)=0.
    Q=0.
    DO 12 I=1,NS
    READ(5,13) DI,DE,LEN(I),ELAS(I),SST(I),VELS(I),DSOI(I)
 13 FORMAT(7E11.5)
    AREA(I)=(DE*DE-DI*DI)*PI/4.
    TD=LEN(I)/VELS(I)
    Q=Q+TD
    ATD(I+1)=Q
    WRITE(6,15)I,DI,DE,AREA(I),ELAS(I),LEN(I)
 15 FORMAT(I8,2X,5(1X,E10.4,1X))
 12 CONTINUE
    WRITE(6,50)
 50 FORMAT('1',27X,24('*'),/,28X,'*',22X,'*',/,28X,'*',3X,
   1'SOIL  PROPERTIES',3X,'*',/28X,'*',22X,'*',/,28X,24('*'),/,
   22('0',/),2X,' SEGMENT',3X,'SOIL STIFFNESS',3X,
   3'PROPAGATION VELOCITY  MAX.ELASTIC DISP.'/'0'/)
    DO 51 I=1,NS
 51 WRITE(6,52)I,SST(I),VELS(I),DSOI(I)
 52 FORMAT(I7,3X,3(3X,E14.7,3X))
    SW=1.
    TM=TS-TI
    CALL CONST
    J7=NS2+1
    K7=2*NS2
 20 TM=TM+TI
    IF(TM.GT.TE)GO TO 999
    IF(SW.EQ.0.)GO TO 22
    NFIRST=0
    DO 21 I=J7,K7
 21 X(I)=0.
 22 PER=PERI
    SW=0.
    XN=1.
    CALL DISP(TM)
    CALL MULT(PER)
    CALL SOLVE(NSYS)
    CALL STRAIN(PER)
    CALL HIGH(XITER,PERI,PER,SW,PERP,XN)
    IF(SW.GT.0.)GO TO 130
    CALL SAVE(TM,TS)
    CALL RECONS(1)
    IF(TM.LT.STTM(ITM).OR.TM.GT.STTM(ITM+1))GO TO 20
    CALL STOPTM(TM)
    IF(TM.GE.STTM(ITM+1))ITM=ITM+2
    GO TO 20
130 CALL ALTER(TM,PER,IN,NFIRST)
    CALL MULT(PER)
    CALL SOLVE(NSYS)
```

```
      CALL STRAIN(PER)
      IF(XN.GT.XITER)GO TO 132
      XN=XN+1.
      NFIRST=1
      PER=PERP+(1.-PERP)*XN/XITER
      IF(PER.GT.1.)PER=1.
      GO TO 130
  132 CALL SAVE(TM,TS)
      CALL RECONS(3)
      IF(TM.LT.STTM(ITM).OR.TM.GT.STTM(ITM+1))GO TO 20
      CALL STOPTM(TM)
      IF(TM.GE.STTM(ITM+1))ITM=ITM+2
      GO TO 20
  999 CALL FINISH(0,0)
      IF(ILIST.EQ.0) GO TO 100
      NTY=NJ +3*NS
      DO 71 K=1,NTY
      J=K+NJ
      IF(ZCC(J).LT.0.) GO TO 72
      ZM(K,1)=ZCC(J)
      ZM(K,3)=0.
      GO TO 71
   72 ZM(K,3)=ZCC(J)
      ZM(K,1)=0.
   71 CONTINUE
      CALL FINISH(1,1)
  100 CONTINUE
      STOP
      END
```

```
C***************************
      SUBROUTINE ALTER(TM,PER,IN,NFIRST)
C
      REAL*8 SYS,SOIL,X,A,B,C,D,E,U
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/ SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/ KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      CALL RECONS(3)
      J=NS2+1
      K=2*NS2
      DO 1 I=J,K
    1 X(I)=0.
      DO 20 I=2,NS
      J=I+NJ
      IF(ABS(Z(J)).LT.DJOI(I))GO TO 10
      K=6*I-8
      A=KJOI(I)
      B=A*DJOI(I)/ABS(Z(J))
      SYS(K)=SYS(K)-A+B
      SYS(K+1)=SYS(K+1)+A-B
      SYS(K+2)=SYS(K+2)+A-B
      SYS(K+3)=SYS(K+3)-A+B
   10 CONTINUE
   20 CONTINUE
      IF(ABS(Z(NJ+1)).LT.DJOI(1))GO TO 30
      A=KJOI(1)
      B=A*DJOI(1)/ABS(Z(NJ+1))
      SOIL(1)=SOIL(1)-KJOI(1)+B
      SYS(1)=SYS(1)-KJOI(1)+B
   30 IF(ABS(Z(NJ2)).LT.DJOI(NJ))GO TO 40
      A=KJOI(NJ)
      B=A*DJOI(NJ)/ABS(Z(NJ2))
      SOIL(NSOI)=SOIL(NSOI)-KJOI(NJ)+B
      SYS(NSYS)=SYS(NSYS)-KJOI(NJ)+B
   40 DO 50 I=1,NS
      J1=I+NJ2
      J2=I+NJ2+NS
      IF((ABS(Z(J1)).LT.DSOI(I)).AND.(ABS(Z(J2)).LT.DSOI(I)))GO TO 60
      K1=6*I-5
      K2=4*I-3
      I1=2*I+NS2-1
      I2=2*I+NS2
      CALL ZETA(ZL,ZR,DSOI(I),Z(J1),Z(J2),LEN(I),NTYPE)
      IF(NTYPE.EQ.2)GO TO 52
   51 U=1.-ZL/LEN(I)
      A=(1.-U*U*U)*SST(I)*LEN(I)/3.
      B=SST(I)*(ZL*ZL/(2.*LEN(I))-ZL*ZL*ZL/(3.*LEN(I)*LEN(I)))
      C=ZL*ZL*ZL*SST(I)/(3.*LEN(I)*LEN(I))
      T=-1.
      IF(Z(J1).LT.0.)T=1.
      D=T*SST(I)*DSOI(I)*(ZL-ZL*ZL/(2.*LEN(I)))
      E=T*SST(I)*DSOI(I)*ZL*ZL/(2.*LEN(I))
```

```
53 SYS(K1)=SYS(K1)-A
   SYS(K1+1)=SYS(K1+1)-B
   SYS(K1+2)=SYS(K1+2)-B
   SYS(K1+3)=SYS(K1+3)-C
   SOIL(K2)=SOIL(K2)-A
   SOIL(K2+1)=SOIL(K2+1)-B
   SOIL(K2+2)=SOIL(K2+2)-B
   SOIL(K2+3)=SOIL(K2+3)-C
   X(I1)=X(I1)-D
   X(I2)=X(I2)-E
   IF(NTYPE.EQ.1)GO TO 60
52 U=1.-ZR/LEN(I)
   A=SST(I)*ZR*ZR*ZR/(3.*LEN(I)*LEN(I))
   B=SST(I)*(ZR*ZR/(2.*LEN(I))-ZR*ZR*ZR/(3.*LEN(I)*LEN(I)))
   C=(1.-U*U*U)*SST(I)*LEN(I)/3.
   T=-1.
   IF(Z(J2).LT.0.)T=1.
   D=T*SST(I)*DSOI(I)*ZR*ZR/(2.*LEN(I))
   E=T*SST(I)*DSOI(I)*(ZR-ZR*ZR/(2.*LEN(I)))
   NTYPE=1
   GO TO 53
60 CONTINUE
50 CONTINUE
   RETURN
   END
```

```
C************************
      SUBROUTINE CCNST
C
      REAL*8 SYS,SOIL,X
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/ SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      N=NSOI-3
      DO 20 I=1,N,4
      J=(I+3)/4
      SOIL(I)=SST(J)*LEN(J)/3.
      SOIL(I+1)=SOIL(I)/2.
      SOIL(I+2)=SOIL(I+1)
      SOIL(I+3)=SOIL(I)
   20 CONTINUE
      SOIL(1)=SOIL(1)+KJOI(1)
      SOIL(NSOI)=SOIL(NSOI)+KJOI(NJ)
      N=NSYS-3
      DO 30 I=1,N,6
      J=(I+5)/6
      A=(9.*ELAS(J)*AREA(J))/(5.*LEN(J))
      B=SST(J)*LEN(J)/3.
      C=KJOI(J)
      D=KJOI(J+1)
      SYS(I)=A+B+C
      SYS(I+1)=(B/2.)-A
      SYS(I+2)=(B/2.)-A
      SYS(I+3)=A+B+D
      SYS(I+4)=-D
      SYS(I+5)=-D
   30 CONTINUE
      DO 40 I=1,NSOI
      J=I+NSOI
      SOIL(J)=SOIL(I)
   40 CONTINUE
      DO 50 I=1,NSYS
      J=I+NSYS
      SYS(J)=SYS(I)
   50 CONTINUE
      RETURN
      END
```

```
C**************************
      SUBROUTINE COMPUT(TM)
C
      REAL*8  SYS,SOIL,X
      REAL*4  KJOI,LEN
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/  ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      XMAX=0.
      DO 13 I=1,NJ
      J=I+NJ
      XMAX=AMAX1(XMAX,ABS(Z(J)))
   13 CONTINUE
      IF(XMAX.GE.ZBC(1)) CALL STORE(XMAX,TM,1,NJ)
      DO 15 K=1,3
      XMAX=0.
      JJ=K+1
      II=K*NS+NJ+1
      DO 17 I=1,NS
      J=I+II
      XMAX=AMAX1(XMAX,ABS(Z(J)))
   17 CONTINUE
      IF(XMAX.GE.ZBC(JJ)) CALL STORE(XMAX,TM,JJ,NS)
   15 CONTINUE
      RETURN
      END
```

```
C*************************************************************
      SUBROUTINE DISP(TM)
      REAL*8 SYS,SOIL,X
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSCI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      DO 6 I=1,NJ
    6 Z(I)=0.
      JOI1=1
      JOI2=NJ
      DO 5 II=1,IPT
      IF(IPT.EQ.1) GO TO 9
      JOI1=JOINT(II,1)
      JOI2=JOINT(II,2)
    9 IF(JOI1.EQ.0)  GO TO 5
      DO 7 I=JOI1,JOI2
      DEL=TM-ATD(I)
      IF(DEL.GT.((IGM-2)/10.).OR.DEL.LE.0.) GO TO 7
      PN=DEL/0.1
      P=PN
      DIF=AINT(PN)+1.-P
      N=INT(P)
      IF(N.EQ.0)GO TO 1
      Z(I)=(GMOVE(N,II)-GMOVE(N+1,II))*DIF+GMOVE(N+1,II)
      GO TO 7
    1 Z(I)=GMOVE(1,II)*(1.-DIF)
    7 CONTINUE
    5 CONTINUE
      RETURN
      END
```

```
C*********************************
      SUBROUTINE FINISH(NTYPE,IP)
C
      REAL*8 SYS,SOIL,X
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON/PROP/ KJOI(31),SSI(30),LEN(30),ELAS(30),AREA(30),
     *DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      IF (NTYPE.EQ.1)GO TO 30
      NTY=3*NS+NJ
      DO 31 J=1,4
      DO 32 I=1,NTY
      ZM(I,J)=ZM(I+NTY,J)
   32 CONTINUE
   31 CONTINUE
   30 XMAX=0.
      XMIN=0.
      IT1=0
      IT2=0
      WRITE(6,1)
    1 FORMAT('1',16X,43('*'),/,17X,'*',41X,'*',/,17X,'*',2X,
     1'RELATIVE DISPLACEMENTS BETWEEN JOINTS',2X,'*',/,17X,
     2'*',41X,'*',/,17X,43('*'),/'0'/,2X,'JOINT',11X,
     3'EXTENSION',10X,'TIME',11X,'CONTRACTION',8X,'TIME'/'0'/)
C
      DO 2 I=1,NJ
      IF(IP.EQ.0) GO TO 50
      ZM(I,2)=ZT(1)
      ZM(I,4)=ZT(1)
   50 CONTINUE
      WRITE(6,3)I,(ZM(I,J),J=1,4)
      IF(ZM(I,1).GT.XMAX) IT1=I
      IF(ZM(I,3).LT.XMIN) IT2=I
      XMAX=AMAX1(XMAX,ZM(I,1))
      XMIN=AMIN1(XMIN,ZM(I,3))
    2 CONTINUE
      WRITE(6,21) XMAX,IT1,XMIN,IT2
      IF(IP.NE.0) CALL GDISP( ZT(1),1,1)
      XMAX=0.
      XMIN=0.
      IT1=0
      IT2=0
      WRITE(6,4)
    4 FORMAT('1',13X,50('*'),/,14X,'*',48X,'*',/,14X,'*',2X,
     1'RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL',2X,'*',/,
     214X,'*',48X,'*',/,14X,'*',20X,'NEAR END',20X,'*',/
     314X,'*',48X,'*',/,14X,50('*'),/'0'/,3X,'PIPE',12X,'POSITIVE',
     410X,'TIME',12X,'NEGATIVE',10X,'TIME',/'0'/)
      DO 5 I=1,NS
      K=I+NJ
      IF(IP.EQ.0) GO TO 51
      ZM(K,2)=ZT(2)
      ZM(K,4)=ZT(2)
```

```
51  CONTINUE
    WRITE(6,3)I,(ZM(K,J),J=1,4)
    IF(ZM(K,1).GT.XMAX) IT1=I
    IF(ZM(K,3).LT.XMIN) IT2=I
    XMAX=AMAX1(XMAX,ZM(K,1))
    XMIN=AMIN1(XMIN,ZM(K,3))
 5  CONTINUE
    WRITE(6,20) XMAX,IT1,XMIN,IT2
    IF(IP.NE.0) CALL GDISP( ZT(2),2,1)
    XMAX=0.
    XMIN=0.
    IT1=0
    IT2=0
    WRITE(6,7)
 7  FORMAT('1',13X,50('*'),/,14X,'*',48X,'*',/,14X,'*',2X,
   1'RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL',2X,'*',/,
   214X,'*',48X,'*',/,14X,'*',20X,' FAR END',20X,'*',/
   314X,'*',48X,'*',/,14X,50('*'),/'0'/,3X,'PIPE',12X,'POSITIVE',
   410X,'TIME',12X,'NEGATIVE',10X,'TIME',/'0'/)
    N3=NJ+NS
    DO 8 I=1,NS
    K=I+N3
    IF(IP.EQ.0) GO TO 52
    ZM(K,2)=ZT(3)
    ZM(K,4)=ZT(3)
52  CONTINUE
    WRITE(6,3)I,(ZM(K,J),J=1,4)
    IF(ZM(K,1).GT.XMAX) IT1=I
    IF(ZM(K,3).LT.XMIN) IT2=I
    XMAX=AMAX1(XMAX,ZM(K,1))
    XMIN=AMIN1(XMIN,ZM(K,3))
 8  CONTINUE
    WRITE(6,20) XMAX,IT1,XMIN,IT2
    IF(IP.NE.0) CALL GDISP( ZT(3),3,1)
    XMAX=0.
    XMIN=0.
    IT1=0
    IT2=0
    WRITE(6,9)
 9  FORMAT('1',25X,26('*'),/,26X,'*',24X,'*',/,26X,'*',2X,
   1'MAXIMUM PIPE STRAINS',2X,'*',/,26X,'*',24X,'*',/,26X,
   226('*'),/'0'/,3X,'PIPE',12X,'TENSILE',11X,'TIME',11X,
   3'COMPRESSIVE',10X,'TIME'/'0'/)
    N=NJ+NS2
    DO 10 I=1,NS
    K=I+N
    IF(IP.EQ.0) GO TO 53
    ZM(K,2)=ZT(4)
    ZM(K,4)=ZT(4)
53  CONTINUE
    ZM(K,1)=ZM(K,1)/LEN(I)
    ZM(K,3)=ZM(K,3)/LEN(I)
    WRITE(6,3)I,(ZM(K,J),J=1,4)
    IF(ZM(K,1).GT.XMAX) IT1=I
    IF(ZM(K,3).LT.XMIN) IT2=I
    XMAX=AMAX1(XMAX,ZM(K,1))
    XMIN=AMIN1(XMIN,ZM(K,3))
10  CONTINUE
```

```
      WRITE(6,20) XMAX,IT1,XMIN,IT2
      IF(IP.NE.0) CALL GDISP( ZT(4),4,1)
    3 FORMAT(I5,2(10X,E15.8,5X,F5.1))
      RETURN
   20 FORMAT(2(/'0'),15X,51('*'),/,16X,'*',49X,'*',/,16X,'*',2X,
     1'MAXIMUM VALUE = ',E13.5,' AT PIPE  NO. ',I2,2X,'*',/,16X,'*',49X,
     2'*',/,16X,'*',2X,'MINIMUM VALUE = ',E13.5,' AT PIPE  NO. ',I2,2X,
     3'*',/,16X,'*',49X,'*',/,16X,51('*'))
   21 FORMAT(2(/'0'),15X,51('*'),/,16X,'*',49X,'*',/,16X,'*',2X,
     1'MAXIMUM VALUE = ',E13.5,' AT JOINT NO. ',I2,2X,'*',/,16X,'*',49X,
     2'*',/,16X,'*',2X,'MINIMUM VALUE = ',E13.5,' AT JOINT NO. ',I2,2X,
     3'*',/,16X,'*',49X,'*',/,16X,51('*'))
      END
```

```
C***********************************
      SUBROUTINE FREEZE(TM,NTY)
      REAL*8 SYS,SOIL,X
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
      DIMENSION ZM1(320,4)
C
      CALL GDISP(TM,0,0)
      DO 10 K=1,NTY
      J=K+NJ
      I=K+NTY
      DO 20 JT=1,4
      ZM1(I,JT)=ZM(I,JT)
   20 CONTINUE
      IF(Z(J).LT.0.) GO TO 4
      ZM(I,1)=Z(J)
      ZM(I,2)=TM
      ZM(I,3)=0.
      ZM(I,4)=TM
      GO TO 10
    4 ZM(I,1)=0.
      ZM(I,2)=TM
      ZM(I,3)=Z(J)
      ZM(I,4)=TM
   10 CONTINUE
      CALL FINISH(0,0)
      DO 30 K=1,NTY
      J=K+NJ
      I=K+NTY
      DO 40 JT=1,4
      ZM(I,JT)=ZM1(I,JT)
   40 CONTINUE
   30 CONTINUE
      RETURN
      END
```

```
C***********************************
      SUBROUTINE GDISP(TM,IZ,IQ)
      REAL*8 SYS,SOIL,X
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
      DIMENSION ZM1(320,4)
C
      IF(IQ.EQ.0) GO TO 50
      DO 51 K=1,NJ
      Z(K)=ZBB(K,IZ)
   51 CONTINUE
   50 CONTINUE
      XMAX=0.
      XMIN=0.
      IT1=0
      IT2=0
      WRITE(6,10)
   10 FORMAT('1',25X,27('*'),/,26X,'*',25X,'*',/,26X,'*',2X,
     1'GROUND  DISPLACEMENTS',2X,'*',/,26X,'*',25X,'*',/,26X,27('*'),
     2/'0'/,2X,'JOINT',11X,'POSITIVE',11X,'TIME',12X,'NEGATIVE',
     410X,'TIME'/'0'/)
      DO 15 I=1,NJ
      IF(Z(I).LT.0.) GO TO 17
      ZM1(I,1)=Z(I)
      ZM1(I,2)=TM
      ZM1(I,3)=0.0
      ZM1(I,4)=TM
      GO TO 15
   17 ZM1(I,3)=Z(I)
      ZM1(I,4)=TM
      ZM1(I,1)=0.0
      ZM1(I,2)=TM
   15 CONTINUE
      DO 18 I=1,NJ
      WRITE(6,3) I,(ZM1(I,J), J=1,4)
      IF(ZM1(I,1).GT.XMAX) IT1=I
      IF(ZM1(I,3).LT.XMIN) IT2=I
      XMAX=AMAX1(XMAX,ZM1(I,1))
      XMIN=AMIN1(XMIN,ZM1(I,3))
   18 CONTINUE
      WRITE(6,21) XMAX,IT1,XMIN,IT2
    3 FORMAT(I5,2(10X,E15.8,5X,F5.1))
   21 FORMAT(2(/'0'),15X,51('*'),/,16X,'*',49X,'*',/,16X,'*',2X,
     1'MAXIMUM VALUE = ',E13.5,' AT JOINT NO. ',I2,2X,'*',/,16X,'*',49X,
     2'*',/,16X,'*',2X,'MINIMUM VALUE = ',E13.5,' AT JOINT NO. ',I2,2X,
     3'*',/,16X,'*',49X,'*',/,16X,51('*'))
      RETURN
      END
```

```
C********************************** 
      SUBROUTINE HIGH(XITER,PERI,PER,SW,PERP,XN)
C
      REAL*8 SYS,SOIL,X
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/ KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30),
     *DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JCINT(4,2)
      DIMENSION H(3)
C
      HIGH1=0.
      DO 1 I=1,NJ
      J=I+NJ
      HJ=ABS(Z(J)/DJOI(I))
      IF(HJ.LT.HIGH1)GO TO 1
      H(1)=HJ
      HIGH1=HJ
    1 CONTINUE
      HIGH1=0.
      DO 2 I=1,NS
      J=I+NJ2
      HJ=ABS(Z(J)/DSOI(I))
      IF(HJ.LT.HIGH1)GO TO 2
      H(2)=HJ
      HIGH1=HJ
    2 CONTINUE
      HIGH1=0.
      NJ2NS=NJ2+NS
      DO 3 I=1,NS
      J=I+NJ2NS
      HJ=ABS(Z(J)/DSOI(I))
      IF(HJ.LT.HIGH1)GO TO 3
      H(3)=HJ
      HIGH1=HJ
    3 CONTINUE
      HIGH1=0.
      DO 5 I=1,3
      IF(H(I).LT.HIGH1)GO TO 4
      HIGH1=H(I)
    4 CONTINUE
    5 CONTINUE
      PERP=PERI/HIGH1
      IF(PERP.LT.1.)GO TO 10
      SW=-1.
    7 KT=3*NS+NJ2
      J=NJ+1
      DO 8 I=J,KT
      Z(I)=Z(I)/PER
    8 CONTINUE
      GO TO 11
   10 PER=PERP+(1.-PERP)*XN/XITER
      IF(PER.GT.1.)PER=1.
      SW=1.
      GO TO 7
```

```
C****************************
      SUBROUTINE MULT(PER)
C
      REAL*8 SYS,SOIL,X
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      DO 1 I=1,NS
      K=2*I
      L=4*I
      X(K-1)=PER*(SOIL(L-3)*Z(I)+SOIL(L-1)*Z(I+1))
      X(K)=PER*(SOIL(L-2)*Z(I)+SOIL(L)*Z(I+1))
    1 CONTINUE
      DO 2 I=1,NS2
      J=I+NS2
      X(I)=X(I)+X(J)
    2 CONTINUE
      RETURN
      END
```

```
C*************************
      SUBROUTINE RECONS(N)
C
      REAL*8 SYS,SCIL,X
      COMMON /MATPIZ/SYS(300),SOIL(300)
      COMMON /VECTCR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),APEA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      GO TO (10,20,30),N
   10 DO 11 I=1,NSYS
      J=NSYS+I
      SYS(I)=SYS(J)
   11 CONTINUE
      GO TO 40
   20 DO 21 I=1,NSOI
      J=I+NSOI
      SOIL(I)=SOIL(J)
   21 CONTINUE
      GO TO 40
   30 DO 31 I=1,NSYS
      J=NSYS+I
      SYS(I)=SYS(J)
   31 CONTINUE
      DO 32 I=1,NSCI
      J=I+NSOI
      SOIL(I)=SOIL(J)
   32 CONTINUE
   40 RETURN
      END
```

```
C*****************************
      SUBROUTINE SAVE(TM,TS)
C
      REAL*8 SYS,SOIL,X
       COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      IF(TM.GT.TS)GO TO 1
      NTY=NJ+3*NS
      NTY1=NTY+1
      NTY2=2*NTY
      DO 5 J=1,4
      DO 2 I=NTY1,NTY2
      ZM(I,J)=0.
    2 CONTINUE
    5 CONTINUE
    1 CONTINUE
      IF(KLIST.EQ.0) GO TO 50
      DO 51 I=1,KLIST
      IF(ABS(TIME(I)-TM).LT.0.001) CALL FREEZE(TM,NTY)
   51 CONTINUE
   50 CONTINUE
      DO 20 K=1,NTY
      J=K+NJ
      I=K+NTY
      IF(Z(J).LT.0.)GO TO 4
      IF(Z(J).LT.ZM(I,1))GO TO 10
      ZM(I,1)=Z(J)
      ZM(I,2)=TM
      GO TO 10
    4 IF(Z(J).GT.ZM(I,3))GO TO 10
      ZM(I,3)=Z(J)
      ZM(I,4)=TM
   10 CONTINUE
   20 CONTINUE
      IF(ILIST.NE.0) CALL COMPUT(TM)
      RETURN
      END
```

```
C*************************
      SUBROUTINE SOLVE(N1)
C
      REAL*8 SYS,SOIL,X
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      N=(N1+2)/3
      DO 1 I=1,N1,3
      J=(I+2)/3
      X(J)=X(J)/SYS(I)
      IF(J.GE.N)GO TO 1
      SYS(I+2)=SYS(I+2)/SYS(I)
      X(J+1)=X(J+1)-X(J)*SYS(I+1)
      SYS(I+3)=SYS(I+3)-SYS(I+2)*SYS(I+1)
    1 CONTINUE
      DO 2 I=1,N1,3
      J=((N1-I)/3)+1
      L=N1-I+1
      IF(J.LE.1)GO TO 2
      X(J-1)=X(J-1)-X(J)*SYS(L-1)
    2 CONTINUE
      RETURN
      END
```

```
C*****************************
      SUBROUTINE START(NS,NJ,TS,TE,TI,PERI,XITER,NSYS)
C
      INTEGER STAR,BLAN
      DIMENSION NTITLE(80)
      DATA STAR/'*'/,BLAN/' '/
C
      IF(NSYS.GT.300)WRITE(6,1)NSYS
    1 FORMAT(' ****WARNING*****    INCREASE DIMENSIONS    ')
      WRITE(6,100)NS,NJ,TS,TE,TI,XITER,PERI
  100 FORMAT('1',/'0',18X,41('*'),/,19X,'*',39X,'*',/,19X,'*',
     13X,'ELASTO-PLASTIC  PIPELINE ANALYSIS    *',/,19X,'*',39X,'*',
     2/19X,41('*'),3(/'0'),20X,38('*'),/,21X,'*',36X,'*',/,21X,'*',
     33X,'NUMBER OF SEGMENTS',I12,3X,'*'/,21X,'*',36X,'*',/,21X,'*',
     43X,'NUMBER OF JOINTS',I14,3X,'*',/,21X,'*',36X,'*',/,21X,'*',
     53X,'INITIAL TIME',F18.2,3X,'*',/,21X,'*',36X,'*',/,21X,'*',
     63X,'FINAL TIME',F20.2,3X,'*',/,21X,'*',36X,'*',/,21X,'*',
     73X,'TIME INTERVAL',F17.2,3X,'*'/21X,'*',36X,'*'/21X,'*',
     83X,'NUMBER OF ITERATIONS',F10.0,3X,'*'/21X,'*',36X,'*'/21X,'*',
     93X,'INITIAL PERCENTAGE',F12.4,3X,'*'/21X,'*',36X,'*'/21X,38('*')
     1,2(/'0'))
      N=37
      NBL=INT((74.-N)/2.)
      NSTR=N+8
      NT=NBL+NSTR
      N1=NBL+1
      N2=N1+1
      N3=N2+3
      N4=N3+N
      N5=N4+2
      J=0
      DO 4 I=1,NBL
    4 NTITLE(I)=BLAN
    2 IF(J.GT.0)WRITE(6,103)(NTITLE(I),I=1,NT)
      J=J+1
      GO TO(10,20,30,20,10,40),J
   10 DO 11 I=N1,NT
   11 NTITLE(I)=STAR
      GO TO 2
   20 DO 21 I=N2,N5
   21 NTITLE(I)=BLAN
      GO TO 2
   30 READ(5,104)K,(NTITLE(I),I=N3,N4)
  104 FORMAT(I1,79A1)
      IF(K.EQ.1)J=1
      GO TO 2
  103 FORMAT(80A1)
   40 RETURN
      END
```

```
C************************************
      SUBROUTINE STOPTM(TM)
C
      REAL*8 SYS,SOIL,X,AD
       COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      NTY=3*NS+NJ
      DO 1 I=1,NTY
      J=I+NJ
      IF(Z(J).LT.0.)GO TO 3
      ZM(I,1)=Z(J)
      ZM(I,2)=TM
      ZM(I,3)=0.
      ZM(I,4)=TM
      GO TO 4
    3 ZM(I,3)=Z(J)
      ZM(I,4)=TM
      ZM(I,2)=TM
      ZM(I,1)=0.
    4 CONTINUE
    1 CONTINUE
      CALL FINISH(1,0)
      RETURN
      END
```

```
C*******************************
      SUBROUTINE STORE(XMAX,TM,I,J)
C
      REAL*8 SYS,SOIL,X
      REAL*4 KJOI,LEN
      COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSOI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      K5=1
      IF(I.EQ.1) K5=0
      ZBC(I)=XMAX
      ZT(I)=TM
      DO 2 K1=1,NJ
      ZBB(K1,I)=Z(K1)
    2 CONTINUE
      DO 5 K1=1,J
      K2=K1+NJ+NS*(I-1) +K5
      ZCC(K2)=Z(K2)
    5 CONTINUE
      RETURN
      END
```

```
C***************************
      SUBROUTINE STRAIN(PER)
C
      REAL*8 SYS,SOIL,X
       COMMON /MATRIZ/SYS(300),SOIL(300)
      COMMON /VECTOR/ X(120),Z(160),ZT(4),ZBC(4),ZCC(160),TIME(5)
      COMMON /PROP/KJOI(31),SST(30),LEN(30),ELAS(30),AREA(30)
     *,DJOI(31),DSCI(30)
      COMMON /DESP/ATD(30)
      COMMON /KONST/ NS,NJ,NS2,NJ2,NSYS,NSOI,ILIST,KLIST,IGM,IPT
      COMMON/MAXIM/ ZM(320,4),ZBB(21,4),GMOVE(600,4),JOINT(4,2)
C
      DO 1 K=2,NS
      J=K+NJ
      I=2*K-2
      Z(J)=X(I+1)-X(I)
    1 CONTINUE
      Z(NJ+1)=X(1)-PER*Z(1)
      Z(NJ2)=PER*Z(NJ)-X(NS2)
      DO 2 K=1,NS
      I=2*K-1
      J=K+NJ2
      Z(J)=PER*Z(K)-X(I)
    2 CONTINUE
      NJ2NS=NJ2+NS
      DO 3 K=1,NS
      L=K+1
      I=2*K
      J=K+NJ2NS
      Z(J)=PER*Z(L)-X(I)
    3 CONTINUE
      NJ2NS2=NJ2+NS2
      DO 4 K=1,NS
      J=K+NJ2NS2
      I=2*K
      Z(J)=X(I)-X(I-1)
    4 CONTINUE
      RETURN
      END
```

```
C**************************************
      SUBROUTINE ZETA(ZL,ZR,D,Z1,Z2,XL,N)
C
      N=4
      ZL=XL*(ABS(Z1)-D)/ABS(Z1-Z2)
      ZR=XL*(ABS(Z2)-D)/ABS(Z1-Z2)
      IF((ZL.GT.0.).AND.(ZR.LE.0.))N=1
      IF((ZR.GT.0.).AND.(ZL.LE.0.))N=2
      IF((ZL.GT.0.).AND.(ZR.GT.0.))N=3
      IF((ABS(ZL)+ABS(ZR)).LT.XL)GO TO 100
      GO TO (10,20,30,40),N
   10 IF(ZL.LE.XL)GO TO 100
      ZL=XL
      GO TO 100
   20 IF(ZR.LE.XL)GO TO 100
      ZR=XL
      GO TO 100
   30 IF(ZR.GT.ZL)GO TO 31
      ZL=XL
      ZR=0.
      GO TO 100
   31 ZL=0.
      ZR=XL
      GO TO 100
   40 WRITE(6,41)ZL,ZR,D,Z1,Z2
   41 FORMAT(1X,'SOMETHING IS WRONG',/ 5E12.4)
  100 RETURN
      END
```

APPENDIX B

EXAMPLE RUN

INPUT FILE

NOTE: See Section III.4 for Description of the input file.

```
SET 1 ---> 3   174
        -> 1     5
SET 2 -    6    12
        -> 13   21
   -> 0.531496  1.015354  1.518503  2.052755  2.630709  3.223228  3.826772  4.464566
      5.120472  5.623622  5.927559  6.030708  6.018503  6.059448  5.922441  5.361417
      4.422834  3.522834  3.056692  2.881889  2.245275  1.074409 -0.333465 -1.576771
     -2.945275 -4.094094 -5.179133 -6.249212 -7.113382 -7.661810 -7.788584 -7.684644
     -7.340552 -6.936615 -6.379922 -5.620866 -4.779921 -4.260236 -3.933858 -3.726771
     -3.629921 -3.574016 -3.527558 -3.652362 -3.468897 -2.984645 -2.498818 -2.454723
     -2.712204 -2.801181 -2.637008 -2.305905 -1.877953 -1.280708 -0.412205  0.344094
      0.822835  1.340550  1.785039  2.062598  2.295669  2.484252  2.723621  2.966928
      3.181102  3.279921  3.434646  3.600787  3.757087  3.867716  3.824409  3.921260
      3.830315  3.587795  3.574409  3.659055  3.590944  3.414567  3.348818  3.302755
      3.136614  2.749999  2.159842  1.475984  0.764961 -0.195276 -1.087794 -1.638582
     -2.118110 -2.599213 -2.932283 -2.926771 -2.611417 -2.124803 -1.568503 -1.087794
     -0.795669 -0.572047 -0.503150 -0.431496 -0.303150 -0.400394 -0.563780 -0.584252
     -0.531496 -0.520079 -0.583071 -0.740157 -0.884646 -0.962992 -1.013386 -0.909055
     -1.024015 -1.485039 -1.902362 -1.696850 -0.853937  0.226772  0.974016  1.675590
      1.998031  1.993306  1.702755  1.266929  0.995276  0.806693  0.542520  0.278346
      0.099606  0.081102  0.086614  0.037795  0.033858 -0.033465 -0.121653 -0.303937
     -0.564173 -0.847638 -1.004330 -1.137794 -1.282677 -1.438976 -1.366929 -1.302755
     -1.317717 -1.307086 -1.364566 -1.409449 -1.451968 -1.636614 -1.838976 -1.924409
     -2.088976 -2.273622 -2.371260 -2.348425 -2.214172 -2.021653 -1.771259 -1.342519
     -0.899606 -0.594094 -0.272441  0.199213  0.650394  0.987402  1.378739  1.809842
      2.112598  2.273622  2.371260  2.486613  2.609055  2.690945
      2.823228  3.032677  3.012598  2.796850  2.551181  2.313779  2.146063  2.112598
      2.103149  2.129921  2.111417  2.146456  2.370078  2.495275  2.423622  2.353936
      2.212204  1.962992  1.697638  1.569685  1.557874  1.427559  1.167322  1.053937
      0.990945  0.801968  0.713779  0.609055  0.528346  0.712992  1.020078  1.172047
      1.048819  0.979134  1.042126  1.048819  1.085039  1.200000  1.177559  1.011810
      0.731890  0.454331  0.089370 -0.191339 -0.423228 -0.733071 -1.025984 -1.206299
     -1.325590 -1.449212 -1.661811 -1.770079 -1.995669 -2.198818 -2.446456 -2.760236
     -2.971653 -3.214172 -3.483858 -3.711417 -3.885433 -4.119684 -4.545275 -4.960236
     -5.103936 -5.198818 -5.184645 -5.356298 -5.499212 -5.633858 -5.784252 -5.711023
     -5.763780 -6.155512 -6.563388 -6.603150 -6.252361 -5.958661 -5.550393 -5.143701
     -4.565353 -3.844488 -3.239763 -2.564960 -1.681496 -0.939764 -0.293307  0.092520
SET 3 -  0.370866  0.773228  1.148031  1.612991  2.139370  2.612991  3.113385  3.658661
      4.237795  4.707479  5.117323  5.393307  5.592126  5.708661  5.709449  5.646063
      5.561417  5.425983  5.243306  5.017323  4.790551  4.490944  4.228346  3.966928
      3.669291  3.399212  3.131495  2.822834  2.568897  2.312204  2.048031  1.807480
      1.611417  1.458661  1.437401  1.448424  1.411811  1.321653  1.296456  1.375196
      1.442913  1.417716  1.381889  1.378346  1.336614  1.184645  1.048425  0.983465
      0.931102  0.868504  0.769292  0.659055  0.595276  0.588583  0.628346  0.670472
      0.654331  0.647638  0.648031  0.617717  0.605512  0.568897  0.505512  0.455512
      0.383465  0.271260  0.124409 -0.013386 -0.113779 -0.229921 -0.390551 -0.532284
     -0.599213 -0.636221 -0.671654 -0.724803 -0.761811 -0.798819 -0.870473 -0.984252
     -1.081495 -1.133464 -1.189369 -1.270865 -1.329921 -1.379133
     -1.567717 -1.589764 -1.595275 -1.622046 -1.635039 -1.630315 -1.644881 -1.680708
     -1.700787 -1.731890 -1.779921 -1.780708 -1.757874 -1.740945 -1.724409 -1.703543
     -1.698424 -1.721259 -1.781495 -1.876771 -2.012992 -2.190157 -2.348818 -2.470078
     -2.581101 -2.655511 -2.699212 -2.703149 -2.666928 -2.617322 -2.524409 -2.399212
     -2.245275 -2.078346 -1.917716 -1.758661 -1.614961 -1.473228 -1.316141 -1.157086
     -1.023228 -0.901181 -0.769292 -0.635433 -0.507480 -0.391339 -0.254724 -0.078740
      0.116929  0.289764  0.429527  0.520079  0.562598  0.546063  0.503937  0.464567
      0.410630  0.353543  0.318110  0.308661  0.320472  0.354331  0.416535  0.494094
      0.545669  0.575984  0.616535  0.683071  0.751575  0.805905  0.881496  0.994882
      1.147637  1.352362  1.594094  1.850787  2.112205  2.371260  2.627559  2.865747
      3.065747  3.216141  3.314173  3.406693  3.509842  3.633070  3.758267  3.857874
      3.923621  3.941731  3.926771  3.888976  3.825590  3.725984  3.634252  3.549212
   |
   v
```

(CONTINUED)

```
                3.453543  3.340550  3.196457  3.016535  2.775590  2.472441  2.139370  1.811024
                1.479134  1.127559  0.770472  0.434252  0.129921 -0.140945 -0.403543 -0.671260
               -0.956299 -1.240551 -1.522440 -1.800393 -2.061023 -2.298819 -2.519685 -2.709449
SET 3 --       -2.862992 -2.972047 -3.042126 -3.074016 -3.070079 -3.038976 -3.000393 -2.970078
               -2.922441 -2.814960 -2.661417 -2.480708 -2.289370 -2.090551 -1.904330 -1.748031
(CONTINUED)    -1.624803 -1.525590 -1.429527 -1.333071 -1.253149 -1.184252 -1.097637 -0.974410
               -0.819291 -0.662205 -0.517323 -0.387795 -0.274409 -0.179528 -0.096457 -0.011811
                0.069291  0.138189  0.176772  0.170472  0.094094  0.022047 -0.069685 -0.206299
               -0.340945 -0.469291 -0.572441 -0.648819 -0.689370 -0.703937 -0.703150 -0.679921
           --> -0.621654 -0.531102 -0.440157 -0.360630 -0.298425 -0.242913
SET 4 ------->   1      2
SET 5 ------>   3.6          12.9
SET 6 ------>   0.01        5.
SET 7 ------>
SET 8 ------>    20    2.3          13.0          0.1
          --> 1       SLIPPAGGE PERMITTED
              1     NORMAL JOINT STIFFNESS
SET 9 --      1              PLASTIC
          -->              NEW FORMULATION
          --> 1000.          1000000000.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
SET 10 --     1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
              1000.          10.
          --> 1000.          1000000000.
          -->    17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
SET 11           17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
                 17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
          -->    17.5      18.0      240.0      30000000.  565.0      2400.0    5.0
```

OUTPUT FILE

```
****************************************
*                                      *
*   ELASTO-PLASTIC  PIPELINE ANALYSIS  *
*                                      *
****************************************



*************************************
*                                   *
*   NUMBER OF  SEGMENTS         20  *
*                                   *
*   NUMBER OF  JOINTS           21  *
*                                   *
*   INITIAL TIME              2.30  *
*                                   *
*   FINAL  TIME              13.00  *
*                                   *
*   TIME  INTERVAL            0.10  *
*                                   *
*   NUMBER OF  ITERATIONS       5.  *
*                                   *
*   INITIAL  PERCENTAGE     0.0100  *
*                                   *
*************************************



********************************************
*                                          *
*         SLIPPAGGE  PERMITTED             *
*                                          *
*       NORMAL  JOINT  STIFFNESS           *
*                                          *
*              PLASTIC                     *
*                                          *
*          NEW  FORMULATION                *
*                                          *
********************************************
```

```
************************
*                      *
*   JOINT PROPERTIES   *
*                      *
************************
```

JOINT	STIFFNESS	MAXIMUM ELASTIC DISPLACEMENT
1	0.1000E+04	0.1000E+10
2	0.1000E+04	0.1000E+02
3	0.1000E+04	0.1000E+02
4	0.1000E+04	0.1000E+02
5	0.1000E+04	0.1000E+02
6	0.1000E+04	0.1000E+02
7	0.1000E+04	0.1000E+02
8	0.1000E+04	0.1000E+02
9	0.1000E+04	0.1000E+02
10	0.1000E+04	0.1000E+02
11	0.1000E+04	0.1000E+02
12	0.1000E+04	0.1000E+02
13	0.1000E+04	0.1000E+02
14	0.1000E+04	0.1000E+02
15	0.1000E+04	0.1000E+02
16	0.1000E+04	0.1000E+02
17	0.1000E+04	0.1000E+02
18	0.1000E+04	0.1000E+02
19	0.1000E+04	0.1000E+02
20	0.1000E+04	0.1000E+02
21	0.1000E+04	0.1000E+10

```
************************
*                      *
*   SOIL  PROPERTIES   *
*                      *
************************
```

SEGMENT	SOIL STIFFNESS	PROPAGATION VELOCITY	MAX.ELASTIC DISP.
1	0.5650000E+03	0.2400000E+04	0.5000000E+01
2	0.5650000E+03	0.2400000E+04	0.5000000E+01
3	0.5650000E+03	0.2400000E+04	0.5000000E+01
4	0.5650000E+03	0.2400000E+04	0.5000000E+01
5	0.5650000E+03	0.2400000E+04	0.5000000E+01
6	0.5650000E+03	0.2400000E+04	0.5000000E+01
7	0.5650000E+03	0.2400000E+04	0.5000000E+01
8	0.5650000E+03	0.2400000E+04	0.5000000E+01
9	0.5650000E+03	0.2400000E+04	0.5000000E+01
10	0.5650000E+03	0.2400000E+04	0.5000000E+01
11	0.5650000E+03	0.2400000E+04	0.5000000E+01
12	0.5650000E+03	0.2400000E+04	0.5000000E+01
13	0.5650000E+03	0.2400000E+04	0.5000000E+01
14	0.5650000E+03	0.2400000E+04	0.5000000E+01
15	0.5650000E+03	0.2400000E+04	0.5000000E+01
16	0.5650000E+03	0.2400000E+04	0.5000000E+01
17	0.5650000E+03	0.2400000E+04	0.5000000E+01
18	0.5650000E+03	0.2400000E+04	0.5000000E+01
19	0.5650000E+03	0.2400000E+04	0.5000000E+01
20	0.5650000E+03	0.2400000E+04	0.5000000E+01

```
****************************
*                          *
*   PIPELINE  PROPERTIES   *
*                          *
****************************
```

PIPE	I.DIAMETER	EX.DIAMETER	AREA	M.ELASTICITY	LENGTH
1	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
2	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
3	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
4	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
5	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
6	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
7	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
8	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
9	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
10	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
11	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
12	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
13	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
14	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
15	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
16	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
17	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
18	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
19	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03
20	0.1750E+02	0.1800E+02	0.1394E+02	0.3000E+08	0.2400E+03

```
**************************
*                        *
*  GROUND  DISPLACEMENTS *
*                        *
**************************
```

JOINT	POSITIVE	TIME	NEGATIVE	TIME
1	0.0	3.6	-0.56209345E+01	3.6
2	0.0	3.6	-0.63799810E+01	3.6
3	0.0	3.6	-0.69366579E+01	3.6
4	0.0	3.6	-0.73405886E+01	3.6
5	0.0	3.6	-0.76846542E+01	3.6
6	0.10200491E+01	3.6	0.0	3.6
7	0.71297228E+00	3.6	0.0	3.6
8	0.52835333E+00	3.6	0.0	3.6
9	0.60906452E+00	3.6	0.0	3.6
10	0.71378839E+00	3.6	0.0	3.6
11	0.80198526E+00	3.6	0.0	3.6
12	0.99095070E+00	3.6	0.0	3.6
13	0.0	3.6	-0.24700689E+01	3.6
14	0.0	3.6	-0.23463054E+01	3.6
15	0.0	3.6	-0.21901426E+01	3.6
16	0.0	3.6	-0.20129833E+01	3.6
17	0.0	3.6	-0.18767643E+01	3.6
18	0.0	3.6	-0.17814913E+01	3.6
19	0.0	3.6	-0.17212572E+01	3.6
20	0.0	3.6	-0.16984243E+01	3.6
21	0.0	3.6	-0.17035427E+01	3.6

```
*****************************************************
*                                                   *
*  MAXIMUM VALUE =   0.10200E+01 AT JOINT NO.   6   *
*                                                   *
*  MINIMUM VALUE =  -0.76847E+01 AT JOINT NO.   5   *
*                                                   *
*****************************************************
```

```
*******************************************
*                                         *
*  RELATIVE DISPLACEMENTS BETWEEN JOINTS  *
*                                         *
*******************************************
```

JOINT	EXTENSION	TIME	CONTRACTION	TIME
1	0.0	3.6	-0.38008475E+00	3.6
2	0.0	3.6	-0.65204412E+00	3.6
3	0.0	3.6	-0.47868705E+00	3.6
4	0.0	3.6	-0.34092492E+00	3.6
5	0.41315107E+01	3.6	0.0	3.6
6	0.41504593E+01	3.6	0.0	3.6
7	0.0	3.6	-0.21190614E+00	3.6
8	0.0	3.6	-0.51873539E-01	3.6
9	0.91346681E-01	3.6	0.0	3.6
10	0.96258223E-01	3.6	0.0	3.6
11	0.12512290E+00	3.6	0.0	3.6
12	0.0	3.6	-0.16171703E+01	3.6
13	0.0	3.6	-0.16501551E+01	3.6
14	0.12675029E+00	3.6	0.0	3.6
15	0.16688210E+00	3.6	0.0	3.6
16	0.15586174E+00	3.6	0.0	3.6
17	0.11531353E+00	3.6	0.0	3.6
18	0.77462852E-01	3.6	0.0	3.6
19	0.41397791E-01	3.6	0.0	3.6
20	0.89756586E-02	3.6	0.0	3.6
21	0.0	3.6	-0.24659904E-02	3.6

```
**************************************************
*                                                *
*  MAXIMUM VALUE =   0.41505E+01 AT JOINT NO.  6 *
*                                                *
*  MINIMUM VALUE =  -0.16502E+01 AT JOINT NO. 13 *
*                                                *
**************************************************
```

```
**************************************************
*                                                *
*  RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL  *
*                                                *
*                   NEAR END                     *
*                                                *
**************************************************
```

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.38006475E+00	3.6	0.0	3.6
2	0.27597326E+00	3.6	0.0	3.6
3	0.20016092E+00	3.6	0.0	3.6
4	0.13873732E+00	3.6	0.0	3.6
5	0.0	3.6	-0.43362083E+01	3.6
6	0.18547052E+00	3.6	0.0	3.6
7	0.90776682E-01	3.6	0.0	3.6
8	0.0	3.6	-0.41264124E-01	3.6
9	0.0	3.6	-0.52195426E-01	3.6
10	0.0	3.6	-0.44135578E-01	3.6
11	0.0	3.6	-0.81413269E-01	3.6
12	0.17242804E+01	3.6	0.0	3.6
13	0.0	3.6	-0.73638737E-01	3.6
14	0.0	3.6	-0.79319000E-01	3.6
15	0.0	3.6	-0.68154614E-01	3.6
16	0.0	3.6	-0.67544103E-01	3.6
17	0.0	3.6	-0.47170825E-01	3.6
18	0.0	3.6	-0.29733490E-01	3.6
19	0.0	3.6	-0.11132203E-01	3.6
20	0.26352175E-02	3.6	0.0	3.6

```
****************************************************
*                                                  *
*  MAXIMUM VALUE =   0.17243E+01 AT PIPE  NO. 12   *
*                                                  *
*  MINIMUM VALUE =  -0.43362E+01 AT PIPE  NO.  5   *
*                                                  *
****************************************************
```

```
*****************************************************
*                                                   *
*  RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL     *
*                                                   *
*                     FAR END                       *
*                                                   *
*****************************************************
```

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.0	3.6	-0.37607110E+00	3.6
2	0.0	3.6	-0.27852631E+00	3.6
3	0.0	3.6	-0.20218760E+00	3.6
4	0.0	3.6	-0.20469737E+00	3.6
5	0.43359299E+01	3.6	0.0	3.6
6	0.0	3.6	-0.12112945E+00	3.6
7	0.0	3.6	-0.93137681E-01	3.6
8	0.39151233E-01	3.6	0.0	3.6
9	0.52122690E-01	3.6	0.0	3.6
10	0.43709613E-01	3.6	0.0	3.6
11	0.10711062E+00	3.6	0.0	3.6
12	0.0	3.6	-0.17237940E+01	3.6
13	0.47431272E-01	3.6	0.0	3.6
14	0.78727424E-01	3.6	0.0	3.6
15	0.88317573E-01	3.6	0.0	3.6
16	0.68142712E-01	3.6	0.0	3.6
17	0.47729339E-01	3.6	0.0	3.6
18	0.30265577E-01	3.6	0.0	3.6
19	0.11610877E-01	3.6	0.0	3.6
20	0.0	3.6	-0.24559904E-02	3.6

```
*****************************************************
*                                                   *
*  MAXIMUM VALUE =   0.43359E+01 AT PIPE  NO.  5    *
*                                                   *
*  MINIMUM VALUE =  -0.17238E+01 AT PIPE  NO. 12    *
*                                                   *
*****************************************************
```

```
*************************
*                       *
*  MAXIMUM PIPE STRAINS *
*                       *
*************************
```

PIPE	TENSILE	TIME	COMPRESSIVE	TIME
1	0.0	3.6	-0.12035868E-04	3.6
2	0.0	3.6	-0.90743479E-05	3.6
3	0.0	3.6	-0.65838731E-05	3.6
4	0.0	3.6	-0.26374673E-05	3.6
5	0.13567435E-03	3.6	0.0	3.6
6	0.0	3.6	-0.19863128E-05	3.6
7	0.0	3.6	-0.29358534E-05	3.6
8	0.12332930E-05	3.6	0.0	3.6
9	0.16904760E-05	3.6	0.0	3.6
10	0.14656407E-05	3.6	0.0	3.6
11	0.18388564E-05	3.6	0.0	3.6
12	0.0	3.6	-0.53927637E-04	3.6
13	0.80550893E-06	3.6	0.0	3.6
14	0.25673917E-05	3.6	0.0	3.6
15	0.28633040E-05	3.6	0.0	3.6
16	0.22168460E-05	3.6	0.0	3.6
17	0.15525457E-05	3.6	0.0	3.6
18	0.97956308E-06	3.6	0.0	3.6
19	0.37484079E-06	3.6	0.0	3.6
20	0.0	3.6	-0.72245712E-07	3.6

```
**************************************************
*                                                *
*   MAXIMUM VALUE =    0.13567E-03 AT PIPE  NO.  5  *
*                                                *
*   MINIMUM VALUE =  -0.53928E-04 AT PIPE  NO. 12  *
*                                                *
**************************************************
```

GROUND DISPLACEMENTS

JOINT	POSITIVE	TIME	NEGATIVE	TIME
1	0.99723220E-01	12.9	0.0	12.9
2	0.27851933E+00	12.9	0.0	12.9
3	0.54269332E+00	12.9	0.0	12.9
4	0.80681670E+00	12.9	0.0	12.9
5	0.99545419E+00	12.9	0.0	12.9
6	0.14484167E+01	12.9	0.0	12.9
7	0.14374142E+01	12.9	0.0	12.9
8	0.14587612E+01	12.9	0.0	12.9
9	0.16115446E+01	12.9	0.0	12.9
10	0.18076372E+01	12.9	0.0	12.9
11	0.20482035E+01	12.9	0.0	12.9
12	0.23123684E+01	12.9	0.0	12.9
13	0.0	12.9	-0.20603549E+01	12.9
14	0.0	12.9	-0.18002186E+01	12.9
15	0.0	12.9	-0.15222635E+01	12.9
16	0.0	12.9	-0.12403727E+01	12.9
17	0.0	12.9	-0.95612502E+00	12.9
18	0.0	12.9	-0.67109656E+00	12.9
19	0.0	12.9	-0.40338671E+00	12.9
20	0.0	12.9	-0.14078379E+00	12.9
21	0.13010210E+00	12.9	0.0	12.9

MAXIMUM VALUE = 0.23124E+01 AT JOINT NO. 12

MINIMUM VALUE = -0.20609E+01 AT JOINT NO. 13

```
****************************************
*                                      *
*  RELATIVE DISPLACEMENTS BETWEEN JOINTS  *
*                                      *
****************************************
```

JOINT	EXTENSION	TIME	CONTRACTION	TIME
1	0.90011001E-01	12.9	0.0	12.9
2	0.21998239E+00	12.9	0.0	12.9
3	0.26254308E+00	12.9	0.0	12.9
4	0.22642851E+00	12.9	0.0	12.9
5	0.31815696E+00	12.9	0.0	12.9
6	0.21929163E+00	12.9	0.0	12.9
7	0.72780214E-02	12.9	0.0	12.9
8	0.86777389E-01	12.9	0.0	12.9
9	0.17344427E+00	12.9	0.0	12.9
10	0.21728414E+00	12.9	0.0	12.9
11	0.23473603E+00	12.9	0.0	12.9
12	0.0	12.9	-0.20299988E+01	12.9
13	0.0	12.9	-0.20315971E+01	12.9
14	0.25178725E+00	12.9	0.0	12.9
15	0.27865756E+00	12.9	0.0	12.9
16	0.28195047E+00	12.9	0.0	12.9
17	0.28345549E+00	12.9	0.0	12.9
18	0.27526861E+00	12.9	0.0	12.9
19	0.26420534E+00	12.9	0.0	12.9
20	0.26475847E+00	12.9	0.0	12.9
21	0.13587534E+00	12.9	0.0	12.9

```
***************************************************
*                                                 *
*  MAXIMUM VALUE =   0.31816E+00 AT JOINT NO.  5  *
*                                                 *
*  MINIMUM VALUE =  -0.20316E+01 AT JOINT NO. 13  *
*                                                 *
***************************************************
```

```
*****************************************************
*                                                   *
*  RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL     *
*                                                   *
*                    NEAR END                       *
*                                                   *
*****************************************************
```

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.0	12.9	-0.90011001E-01	12.9
2	0.0	12.9	-0.13188833E+00	12.9
3	0.0	12.9	-0.13128263E+00	12.9
4	0.0	12.9	-0.94513552E-01	12.9
5	0.0	12.9	-0.22489661E+00	12.9
6	0.70627965E-02	12.9	0.0	12.9
7	0.0	12.9	-0.11214357E-01	12.9
8	0.0	12.9	-0.76736271E-01	12.9
9	0.0	12.9	-0.97986877E-01	12.9
10	0.0	12.9	-0.11994451E+00	12.9
11	0.0	12.9	-0.11504936E+00	12.9
12	0.21784506E+01	12.9	0.0	12.9
13	0.0	12.9	-0.14683074E+00	12.9
14	0.0	12.9	-0.13863438E+00	12.9
15	0.0	12.9	-0.14041895E+00	12.9
16	0.0	12.9	-0.14157963E+00	12.9
17	0.0	12.9	-0.14189750E+00	12.9
18	0.0	12.9	-0.13324982E+00	12.9
19	0.0	12.9	-0.13079214E+00	12.9
20	0.0	12.9	-0.13397443E+00	12.9

```
*****************************************************
*                                                   *
*  MAXIMUM VALUE =   0.21785E+01 AT PIPE  NO. 12    *
*                                                   *
*  MINIMUM VALUE =  -0.22490E+00 AT PIPE  NO.  5    *
*                                                   *
*****************************************************
```

```
**************************************************
*                                                *
*  RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL  *
*                                                *
*                    FAR END                     *
*                                                *
**************************************************
```

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.88093996E-01	12.9	0.0	12.9
2	0.13126045E+00	12.9	0.0	12.9
3	0.13181496E+00	12.9	0.0	12.9
4	0.93260288E-01	12.9	0.0	12.9
5	0.22635442E+00	12.9	0.0	12.9
6	0.0	12.9	-0.39363317E-02	12.9
7	0.10041099E-01	12.9	0.0	12.9
8	0.75457335E-01	12.9	0.0	12.9
9	0.97339630E-01	12.9	0.0	12.9
10	0.11968666E+00	12.9	0.0	12.9
11	0.14845222E+00	12.9	0.0	12.9
12	0.0	12.9	-0.21784277E+01	12.9
13	0.11315280E+00	12.9	0.0	12.9
14	0.13823861E+00	12.9	0.0	12.9
15	0.14037085E+00	12.9	0.0	12.9
16	0.14155799E+00	12.9	0.0	12.9
17	0.14201880E+00	12.9	0.0	12.9
18	0.13341320E+00	12.9	0.0	12.9
19	0.13078403E+00	12.9	0.0	12.9
20	0.13587534E+00	12.9	0.0	12.9

```
**************************************************
*                                                *
*  MAXIMUM VALUE =   0.22635E+00 AT PIPE  NO.  5 *
*                                                *
*  MINIMUM VALUE =  -0.21784E+01 AT PIPE  NO. 12 *
*                                                *
**************************************************
```

```
**************************
*                        *
*  MAXIMUM PIPE STRAINS  *
*                        *
**************************
```

PIPE	TENSILE	TIME	COMPRESSIVE	TIME
1	0.28793474E-05	12.9	0.0	12.9
2	0.42704978E-05	12.9	0.0	12.9
3	0.42740066E-05	12.9	0.0	12.9
4	0.31817945E-05	12.9	0.0	12.9
5	0.71304912E-05	12.9	0.0	12.9
6	0.0	12.9	-0.14617651E-07	12.9
7	0.38152649E-06	12.9	0.0	12.9
8	0.24573446E-05	12.9	0.0	12.9
9	0.31914760E-05	12.9	0.0	12.9
10	0.38972157E-05	12.9	0.0	12.9
11	0.27629221E-05	12.9	0.0	12.9
12	0.0	12.9	-0.68096808E-04	12.9
13	0.27203732E-05	12.9	0.0	12.9
14	0.45083298E-05	12.9	0.0	12.9
15	0.45871584E-05	12.9	0.0	12.9
16	0.46255827E-05	12.9	0.0	12.9
17	0.46328396E-05	12.9	0.0	12.9
18	0.43610706E-05	12.9	0.0	12.9
19	0.42777328E-05	12.9	0.0	12.9
20	0.43166892E-05	12.9	0.0	12.9

```
****************************************************
*                                                  *
*  MAXIMUM VALUE =   0.71305E-05 AT PIPE  NO.  5   *
*                                                  *
*  MINIMUM VALUE =  -0.68097E-04 AT PIPE  NO. 12   *
*                                                  *
****************************************************
```

RELATIVE DISPLACEMENTS BETWEEN JOINTS

JOINT	EXTENSION	TIME	CONTRACTION	TIME
1	0.70547670E+00	2.3	-0.54126036E+00	11.8
2	0.13151283E+01	2.4	-0.95166320E+00	11.8
3	0.13199272E+01	2.5	-0.95415992E+00	11.9
4	0.13175297E+01	2.6	-0.93640739E+00	12.0
5	0.41504602E+01	3.5	-0.50188160E+01	8.0
6	0.41504593E+01	3.6	-0.50188284E+01	8.1
7	0.38749605E+00	6.9	-0.80546683E+00	9.1
8	0.41673100E+00	7.0	-0.80826825E+00	9.2
9	0.41694671E+00	7.1	-0.80831593E+00	9.3
10	0.41705024E+00	7.2	-0.80813152E+00	9.4
11	0.43188918E+00	7.3	-0.78499711E+00	9.5
12	0.39317036E+01	8.6	-0.21140690E+01	2.4
13	0.39317036E+01	8.7	-0.21140690E+01	2.5
14	0.33649874E+00	11.9	-0.23012584E+00	9.0
15	0.35267168E+00	12.0	-0.25898510E+00	9.1
16	0.35278988E+00	12.1	-0.25918829E+00	9.2
17	0.35279077E+00	12.2	-0.25913967E+00	9.3
18	0.35279065E+00	12.3	-0.25918967E+00	9.4
19	0.35278237E+00	12.4	-0.25918353E+00	9.5
20	0.35161185E+00	12.5	-0.25827801E+00	9.6
21	0.17907459E+00	12.6	-0.13114548E+00	9.6

MAXIMUM VALUE = 0.41505E+01 AT JOINT NO. 5

MINIMUM VALUE = -0.50188E+01 AT JOINT NO. 6

```
*****************************************************
*                                                   *
*  RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL     *
*                                                   *
*                    NEAR END                       *
*                                                   *
*****************************************************
```

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.54126036E+00	11.8	-0.70547670E+00	2.3
2	0.53854460E+00	11.9	-0.70095348E+00	2.4
3	0.53838962E+00	12.0	-0.70087337E+00	2.5
4	0.52232730E+00	12.1	-0.69843853E+00	2.6
5	0.50907497E+01	8.0	-0.43362083E+01	3.6
6	0.43705285E+00	9.0	-0.24198496E+00	8.0
7	0.43975365E+00	9.1	-0.21150935E+00	6.9
8	0.43973315E+00	9.2	-0.21129441E+00	7.0
9	0.43972981E+00	9.3	-0.21129012E+00	7.1
10	0.43954915E+00	9.4	-0.21139014E+00	7.2
11	0.41624933E+00	9.5	-0.22917563E+00	8.5
12	0.21784506E+01	12.9	-0.40836296E+01	8.7
13	0.16067046E+00	8.9	-0.19467640E+00	11.9
14	0.13040328E+00	9.0	-0.17802387E+00	12.0
15	0.13018972E+00	9.1	-0.17790216E+00	12.1
16	0.13018817E+00	9.2	-0.17790127E+00	12.2
17	0.13018817E+00	9.3	-0.17790127E+00	12.3
18	0.13018811E+00	9.4	-0.17790121E+00	12.4
19	0.13018197E+00	9.5	-0.17789274E+00	12.5
20	0.12926972E+00	9.6	-0.17664331E+00	12.6

```
*****************************************************
*                                                   *
*  MAXIMUM VALUE =   0.50907E+01 AT PIPE  NO.  5    *
*                                                   *
*  MINIMUM VALUE =  -0.43362E+01 AT PIPE  NO.  5    *
*                                                   *
*****************************************************
```

RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL

FAR END

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.69704115E+00	2.3	-0.53520715E+00	11.8
2	0.70144558E+00	2.4	-0.53784764E+00	11.9
3	0.70150405E+00	2.5	-0.53798878E+00	12.0
4	0.70401156E+00	2.6	-0.55441880E+00	12.1
5	0.43359299E+01	3.6	-0.50932665E+01	8.0
6	0.19415951E+00	4.8	-0.44285494E+00	9.0
7	0.21238554E+00	6.9	-0.44019920E+00	9.1
8	0.21259874E+00	7.0	-0.44021934E+00	9.2
9	0.21259630E+00	7.1	-0.44021970E+00	9.3
10	0.21248847E+00	7.2	-0.44040412E+00	9.4
11	0.19720632E+00	7.3	-0.46421874E+00	9.5
12	0.40828381E+01	8.7	-0.21784277E+01	12.9
13	0.16137624E+00	11.9	-0.10038328E+00	8.9
14	0.17766881E+00	12.0	-0.12999624E+00	9.0
15	0.17778796E+00	12.1	-0.13020527E+00	9.1
16	0.17778879E+00	12.2	-0.13020670E+00	9.2
17	0.17778879E+00	12.3	-0.13020670E+00	9.3
18	0.17778885E+00	12.4	-0.13020676E+00	9.4
19	0.17779750E+00	12.5	-0.13021308E+00	9.5
20	0.17907459E+00	12.6	-0.13114548E+00	9.6

MAXIMUM VALUE = 0.43359E+01 AT PIPE NO. 5

MINIMUM VALUE = -0.50933E+01 AT PIPE NO. 5

```
**************************
*                        *
*  MAXIMUM PIPE STRAINS  *
*                        *
**************************
```

PIPE	TENSILE	TIME	COMPRESSIVE	TIME
1	0.22369553E-04	2.3	-0.17149941E-04	11.8
2	0.22775581E-04	2.4	-0.17393322E-04	11.9
3	0.22775377E-04	2.5	-0.17382874E-04	12.0
4	0.22650362E-04	2.8	-0.15904050E-04	12.1
5	0.13567435E-03	3.6	-0.15934890E-03	8.0
6	0.70221822E-05	4.8	-0.14502521E-04	9.0
7	0.68381978E-05	6.9	-0.14258467E-04	9.1
8	0.68577274E-05	7.0	-0.14260340E-04	9.2
9	0.68578374E-05	7.1	-0.14260195E-04	9.3
10	0.68672043E-05	7.2	-0.14243581E-04	9.4
11	0.87862318E-05	8.5	-0.12098920E-04	9.5
12	0.12777025E-03	8.7	-0.68096808E-04	12.9
13	0.42919810E-05	11.9	-0.36854417E-05	4.6
14	0.57916377E-05	12.0	-0.42327911E-05	9.0
15	0.58025998E-05	12.1	-0.42520278E-05	9.1
16	0.58026790E-05	12.2	-0.42521624E-05	9.2
17	0.58026790E-05	12.3	-0.42521633E-05	9.3
18	0.58026726E-05	12.4	-0.42521606E-05	9.4
19	0.58018932E-05	12.5	-0.42515921E-05	9.5
20	0.56868867E-05	12.6	-0.41576249E-05	9.6

```
**********************************************
*                                            *
*  MAXIMUM VALUE =   0.13567E-03 AT PIPE  NO.  5  *
*                                            *
*  MINIMUM VALUE =  -0.15935E-03 AT PIPE  NO.  5  *
*                                            *
**********************************************
```

```
*******************************************
*                                         *
*  RELATIVE DISPLACEMENTS BETWEEN JOINTS  *
*                                         *
*******************************************
```

JOINT	EXTENSION	TIME	CONTRACTION	TIME
1	0.82899809E-01	8.1	0.0	8.1
2	0.10515070E+00	8.1	0.0	8.1
3	0.56267459E-01	8.1	0.0	8.1
4	0.83658636E-01	8.1	0.0	8.1
5	0.0	8.1	-0.49530792E+01	8.1
6	0.0	8.1	-0.50188284E+01	8.1
7	0.18656951E+00	8.1	0.0	8.1
8	0.39538246E+00	8.1	0.0	8.1
9	0.22089428E+00	8.1	0.0	8.1
10	0.0	8.1	-0.80054924E-02	8.1
11	0.61084654E-01	8.1	0.0	8.1
12	0.32312059E+01	8.1	0.0	8.1
13	0.31237717E+01	8.1	0.0	8.1
14	0.0	8.1	-0.44212338E-01	8.1
15	0.0	8.1	-0.53133883E-01	8.1
16	0.0	8.1	-0.35465088E-01	8.1
17	0.0	8.1	-0.40922213E-01	8.1
18	0.0	8.1	-0.64184487E-01	8.1
19	0.0	8.1	-0.69405437E-01	8.1
20	0.0	8.1	-0.47769777E-01	8.1
21	0.0	8.1	-0.17086506E-01	8.1

```
***************************************************
*                                                 *
*  MAXIMUM VALUE =   0.32312E+01 AT JOINT NO. 12  *
*                                                 *
*  MINIMUM VALUE =  -0.50188E+01 AT JOINT NO.  6  *
*                                                 *
***************************************************
```

GROUND DISPLACEMENTS

JOINT	POSITIVE	TIME	NEGATIVE	TIME
1	0.31366739E+01	8.1	0.0	8.1
2	0.33027716E+01	8.1	0.0	8.1
3	0.33488417E+01	8.1	0.0	8.1
4	0.34146309E+01	8.1	0.0	8.1
5	0.35909691E+01	8.1	0.0	8.1
6	0.0	8.1	-0.66031351E+01	8.1
7	0.0	8.1	-0.65632381E+01	8.1
8	0.0	8.1	-0.61553679E+01	8.1
9	0.0	8.1	-0.57637596E+01	8.1
10	0.0	8.1	-0.57110500E+01	8.1
11	0.0	8.1	-0.57841969E+01	8.1
12	0.0	8.1	-0.56338100E+01	8.1
13	0.75155091E+00	8.1	0.0	8.1
14	0.68304765E+00	8.1	0.0	8.1
15	0.61652136E+00	8.1	0.0	8.1
16	0.57597381E+00	8.1	0.0	8.1
17	0.54565167E+00	8.1	0.0	8.1
18	0.49406916E+00	8.1	0.0	8.1
19	0.41651505E+00	8.1	0.0	8.1
20	0.35432065E+00	8.1	0.0	8.1
21	0.32046837E+00	8.1	0.0	8.1

MAXIMUM VALUE = 0.35910E+01 AT JOINT NO. 5

MINIMUM VALUE = -0.66031E+01 AT JOINT NO. 6

```
*************************************************
*                                               *
*  RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL *
*                                               *
*                  NEAR END                     *
*                                               *
*************************************************
```

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.0	8.0	-0.23187604E-01	8.0
2	0.0	8.0	-0.33234030E-01	8.0
3	0.0	8.0	-0.87577403E-01	8.0
4	0.33401626E-02	8.0	0.0	8.0
5	0.50907497E+01	8.0	0.0	8.0
6	0.0	8.0	-0.24198496E+00	8.0
7	0.0	8.0	-0.19403309E+00	8.0
8	0.0	8.0	-0.24556484E-01	8.0
9	0.36096551E-01	8.0	0.0	8.0
10	0.0	8.0	-0.75819135E-01	8.0
11	0.0	8.0	-0.88658631E-01	8.0
12	0.0	8.0	-0.30787868E+01	8.0
13	0.55914022E-01	8.0	0.0	8.0
14	0.20226926E-01	8.0	0.0	8.0
15	0.15141994E-01	8.0	0.0	8.0
16	0.25861889E-01	8.0	0.0	8.0
17	0.38665753E-01	8.0	0.0	8.0
18	0.30817013E-01	8.0	0.0	8.0
19	0.16675320E-01	8.0	0.0	8.0
20	0.57549179E-02	8.0	0.0	8.0

```
**************************************************
*                                                *
*  MAXIMUM VALUE =   0.50907E+01 AT PIPE  NO.  5 *
*                                                *
*  MINIMUM VALUE =  -0.30788E+01 AT PIPE  NO. 12 *
*                                                *
**************************************************
```

```
**************************
*                        *
*  GROUND  DISPLACEMENTS *
*                        *
**************************
```

JOINT	POSITIVE	TIME	NEGATIVE	TIME
1	0.33027716E+01	8.0	0.0	8.0
2	0.33488417E+01	8.0	0.0	8.0
3	0.34146309E+01	8.0	0.0	8.0
4	0.35909691E+01	8.0	0.0	8.0
5	0.36590233E+01	8.0	0.0	8.0
6	0.0	8.0	-0.65632381E+01	8.0
7	0.0	8.0	-0.61553679E+01	8.0
8	0.0	8.0	-0.57637606E+01	8.0
9	0.0	8.0	-0.57110500E+01	8.0
10	0.0	8.0	-0.57841969E+01	8.0
11	0.0	8.0	-0.56338100E+01	8.0
12	0.0	8.0	-0.54991617E+01	8.0
13	0.68304765E+00	8.0	0.0	8.0
14	0.61652136E+00	8.0	0.0	8.0
15	0.57597381E+00	8.0	0.0	8.0
16	0.54565167E+00	8.0	0.0	8.0
17	0.49406916E+00	8.0	0.0	8.0
18	0.41651505E+00	8.0	0.0	8.0
19	0.35432065E+00	8.0	0.0	8.0
20	0.32046837E+00	8.0	0.0	8.0
21	0.30866385E+00	8.0	0.0	8.0

```
************************************************
*                                              *
*  MAXIMUM VALUE =   0.36590E+01 AT JOINT NO. 5 *
*                                              *
*  MINIMUM VALUE =  -0.55632E+01 AT JOINT NO. 6 *
*                                              *
************************************************
```

```
***************************************************
*                                                 *
*  RELATIVE DISPLACEMENTS BETWEEN PIPE AND SOIL   *
*                                                 *
*                   FAR END                       *
*                                                 *
***************************************************
```

PIPE	POSITIVE	TIME	NEGATIVE	TIME
1	0.22704549E-01	8.0	0.0	8.0
2	0.32291111E-01	8.0	0.0	8.0
3	0.88095248E-01	8.0	0.0	8.0
4	0.71933746E-01	8.0	0.0	8.0
5	0.0	8.0	-0.50932665E+01	8.0
6	0.16513467E+00	8.0	0.0	8.0
7	0.19607633E+00	8.0	0.0	8.0
8	0.27931090E-01	8.0	0.0	8.0
9	0.0	8.0	-0.36792599E-01	8.0
10	0.73995709E-01	8.0	0.0	8.0
11	0.44984352E-01	8.0	0.0	8.0
12	0.30802536E+01	8.0	0.0	8.0
13	0.0	8.0	-0.10848891E-01	8.0
14	0.0	8.0	-0.20164527E-01	8.0
15	0.0	8.0	-0.15059184E-01	8.0
16	0.0	8.0	-0.25518768E-01	8.0
17	0.0	8.0	-0.38588744E-01	8.0
18	0.0	8.0	-0.31135522E-01	8.0
19	0.0	8.0	-0.17044224E-01	8.0
20	0.0	8.0	-0.60026534E-02	8.0

```
***************************************************
*                                                 *
*  MAXIMUM VALUE =  0.30803E+01 AT PIPE  NO. 12   *
*                                                 *
*  MINIMUM VALUE = -0.50933E+01 AT PIPE  NO.  5   *
*                                                 *
***************************************************
```

```
***************************
*                         *
*  GROUND  DISPLACEMENTS  *
*                         *
***************************
```

JOINT	POSITIVE	TIME	NEGATIVE	TIME
1	0.33027716E+01	8.0	0.0	8.0
2	0.33488417E+01	8.0	0.0	8.0
3	0.34146309E+01	8.0	0.0	8.0
4	0.35909691E+01	8.0	0.0	8.0
5	0.36590233E+01	8.0	0.0	8.0
6	0.0	8.0	-0.65632381E+01	8.0
7	0.0	8.0	-0.61553679E+01	8.0
8	0.0	8.0	-0.57637606E+01	8.0
9	0.0	8.0	-0.57110500E+01	8.0
10	0.0	8.0	-0.57841969E+01	8.0
11	0.0	8.0	-0.56338100E+01	8.0
12	0.0	8.0	-0.54991617E+01	8.0
13	0.68304765E+00	8.0	0.0	8.0
14	0.61652136E+00	8.0	0.0	8.0
15	0.57597381E+00	8.0	0.0	8.0
16	0.54565167E+00	8.0	0.0	8.0
17	0.49406916E+00	8.0	0.0	8.0
18	0.41651505E+00	8.0	0.0	8.0
19	0.35432065E+00	8.0	0.0	8.0
20	0.32046837E+00	8.0	0.0	8.0
21	0.30866385E+00	8.0	0.0	8.0

```
*************************************************
*                                               *
*  MAXIMUM VALUE =   0.36590E+01 AT JOINT NO.  5 *
*                                               *
*  MINIMUM VALUE =  -0.65632E+01 AT JOINT NO.  6 *
*                                               *
*************************************************
```

```
**************************
*                        *
*  MAXIMUM PIPE STRAINS  *
*                        *
**************************
```

PIPE	TENSILE	TIME	COMPRESSIVE	TIM
1	0.74142099E-06	8.0	0.0	8.0
2	0.11003358E-05	8.0	0.0	8.0
3	0.27728511E-05	8.0	0.0	8.0
4	0.0	8.0	-0.22474951E-05	8.0
5	0.0	8.0	-0.15934890E-03	8.0
6	0.31275022E-05	8.0	0.0	8.0
7	0.62408526E-05	8.0	0.0	8.0
8	0.92898495E-06	8.0	0.0	8.0
9	0.0	8.0	-0.10736076E-05	8.0
10	0.23827570E-05	8.0	0.0	8.0
11	0.41888452E-05	8.0	0.0	8.0
12	0.96534073E-04	8.0	0.0	8.0
13	0.98592864E-06	8.0	0.0	8.0
14	0.0	8.0	-0.65038813E-06	8.0
15	0.0	8.0	-0.50396557E-06	8.0
16	0.0	8.0	-0.84106159E-06	8.0
17	0.0	8.0	-0.12483606E-05	8.0
18	0.0	8.0	-0.10077947E-05	8.0
19	0.0	8.0	-0.55304702E-06	8.0
20	0.0	8.0	-0.19561730E-06	8.0

```
****************************************************
*                                                  *
*  MAXIMUM VALUE =   0.96534E-04 AT PIPE  NO. 12   *
*                                                  *
*  MINIMUM VALUE =  -0.15935E-03 AT PIPE  NO.  5   *
*                                                  *
****************************************************
```

```
**************************
*                        *
*  GROUND DISPLACEMENTS  *
*                        *
**************************
```

JOINT	POSITIVE	TIME	NEGATIVE	TIME
1	0.33027716E+01	8.0	0.0	8.0
2	0.33488417E+01	8.0	0.0	8.0
3	0.34146309E+01	8.0	0.0	8.0
4	0.35909691E+01	8.0	0.0	8.0
5	0.36590233E+01	8.0	0.0	8.0
6	0.0	8.0	-0.65632381E+01	8.0
7	0.0	8.0	-0.61553679E+01	8.0
8	0.0	8.0	-0.57637606E+01	8.0
9	0.0	8.0	-0.57110500E+01	8.0
10	0.0	8.0	-0.57841969E+01	8.0
11	0.0	8.0	-0.56338100E+01	8.0
12	0.0	8.0	-0.54991617E+01	8.0
13	0.68304765E+00	8.0	0.0	8.0
14	0.61652136E+00	8.0	0.0	8.0
15	0.57597381E+00	8.0	0.0	8.0
16	0.54565167E+00	8.0	0.0	8.0
17	0.49406916E+00	8.0	0.0	8.0
18	0.41651505E+00	8.0	0.0	8.0
19	0.35432065E+00	8.0	0.0	8.0
20	0.32046837E+00	8.0	0.0	8.0
21	0.30866385E+00	8.0	0.0	8.0

```
**************************************************
*                                                *
*  MAXIMUM VALUE =   0.36590E+01 AT JOINT NO.  5 *
*                                                *
*  MINIMUM VALUE =  -0.65632E+01 AT JOINT NO.  6 *
*                                                *
**************************************************
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LIST OF TECHNICAL REPORT ON LIFELINE EARTHQUAKE ENGINEERING

Sponsored by the National Science Foundation
Award No. CEE-8025172 and CEE-8209241

No. 1. Leon Ru-Liang Wang, Tadayoshi Okubo, Eiichi Kuribayashi, Toshio Iwasaki and Osumu Ueda
Lifeline Earthquake Engineering Literatures in Japan
October, 1981

No. 2. Leon Ru-Liang Wang
Tsukuba Science City and Its Magnificent Civil and Earthquake Engineering Research Facilities
November, 1981

No. 3. Leon Ru-Liang Wang, Kazuhiko Kawashima, Yaw-Huei Yeh and Koh Aizawa
Study of Ground Strains from Strong Motion Data for Lifeline Application
December, 1981

No. 4. Leon Ru-Liang Wang
Field Investigation and Analysis of Buried Pipelines Under Various Seismic Environments
June, 1982

No. 5. Leon Ru-Liang Wang and Yaw-Huei Yeh
Seismic Performance Evaluation of Lifelines
November, 1982 (Final Report for Award No. CEE-8025172)

No. 6. Leon Ru-Liang Wang and Afisu Olabimtan
General Quasi-Static Seismic Analysis of Buried Straight Piping Systems
September, 1983